Evaluating remotely sensed images for use in inventorying roadway infrastructure features

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This is to certify that the Master's thesis of

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has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

To my parents

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ABSTRACT

Many different methods of inventory data collection are used by transportation agencies in the United States, but are often time consuming and labor intensive. With data needs increasing for transportation agencies, there is a need for more efficient methods of data collection. This research describes the application of remote sensing for inventorying transportation features. Remote sensing is the process of detecting or monitoring an area usually from the air or from space by measuring reflected or emitted radiation. A pilot study was conducted to evaluate the feasibility of using remotely sensed images in the form of aerial or satellite photography for collection of roadway inventory features. As part of the study, aerial photographs of various resolutions were used to extract features and their accuracy evaluated to determine suitability for inventory purposes. The percentage of data elements that can be extracted from these images and the variation in locating them were tested as part of the study. The accuracy of linear measurements from these images was also evaluated. The methods of data extraction and recommendations on required resolutions are also provided.

CHAPTER 1. INTRODUCTION

In order to effectively manage and maintain the nation's transportation infrastructure, accurate inventory and condition data are required. Up-to-date information helps to identify safety or operationally deficient elements, prioritize maintenance needs, and monitor conditions *(1)*. As a result, all Department of Transportation's (DOTs) in the United States maintain some type of roadway feature inventory *(2)*. Roadway inventory data are used by DOTs for a variety of purposes including traffic safety, construction projects, traffic engineering studies, evaluation of maintenance needs, and planning. Inventory data are also collected and maintained to meet Federal data reporting requirements. Such data are used by the Federal Highway Administration (FHWA) as informational support for the "Condition and Performance Report" to Congress, as well as data that appears in various FHWA publications. Inventory data are also used by other agencies, including state and local agencies, business and industry, educational institutions, the media, and the general public *(3)*.

Inventory data are also necessary to support the numerous functions within DOTs as well as state and local transportation agencies that also utilize such data. However, most data collection methods, which include manual methods, global positioning systems (GPS), and video or photolog vans, are conducted in the field, requiring significant time and resources to cover even a short length of roadway. This is problematic since both state DOTs and local agencies are responsible for significant street network systems. Iowa, for example, has a surface street system covering approximately 110,000 linear miles. As a result, resource constraints often dictate that only minimal inventory data elements, such as pavement condition or number of lanes, are collected and reported system wide. Other data are collected at the corridor level as needed for specific uses, such as the planning of new construction or evaluation of high accident locations. To meet data and reporting needs, a sampling of subsets of roadway segments is often used and then extrapolated to provide system wide estimates.

While sampling may provide adequate information for some uses, other types of applications or analyses are limited by the inability to cost-effectively collect comprehensive data. Traffic studies, safety studies, and evaluation of access control require more comprehensive data than is provided by sampling. Safety studies in particular could benefit from more detailed data. Many aspects of the roadway have been correlated to the occurrence of accidents. For example, a narrow bridge width to approaching roadway width ratio has been associated with increase in accidents *(4)*. Other roadway features such as lane width, shoulder width, and location of utility poles or other fixed objects along the roadway influence likelihood and severity of accidents *(2)*. However, even with crash data that has been accurately spatially located, it is almost impossible to evaluate roadway deficiencies without a supporting database of roadway information. In-field data collection may also pose a safety concern for workers who at times are located on or near busy roadways. Traffic may also be disrupted by data collection efforts.

Research Objectives and Scope of Work

The primary objective of this research is to evaluate remotely sensed images for use in inventorying transportation infrastructure features, by measuring the accuracy with which features can be extracted. Images collected from either an airplane or satellite can be obtained fairly rapidly for large areas without having to locate on road, which can cause interference with traffic. With the launching of the IKONOS satellite, resolutions of 1 meter can be practically obtained from space. Image resolutions as low as 1-inch are possible with aerial photography. Since cost typically decreases as resolution decreases, one of the goals of this research was to test images at different levels of resolution and make recommendations on the minimum resolution necessary for the collection of specific inventory features. This is especially important since many agencies already have access to low-resolution images, such as the United States Geological Survey (USGS) Digital Orthophoto Quarter Quads (DOQQ). Besides the advantage of more rapid data collection, the use of remote sensing may allow for the collection of data which was previously difficult and expensive to obtain using conventional methods. With the increase in the size of transportation inventories, it is preferable to store data in digital format, for the longer life of data than conventional storage and easy retrieval. This is facilitated by the use of remote sensing and Geographic Information System (GIS) in tandem.

To accomplish the objective stated, the scope of research included the following:

- Identify inventory elements currently collected by transportation agencies or those that agencies are considering.

- Identify current methodologies for inventory data collection and evaluate the advantages and disadvantages of each.
- Conduct a pilot study to evaluate which inventory elements can be located and/or measured from aerial photographs at different resolutions.
- Evaluate the spatial accuracy of aerial photographs at different resolutions.
- Evaluate the advantages and disadvantages of using remotely sensed images for data collection (feature recognition, accuracy and observer variation).
- Make recommendations on the level of resolution necessary for collection of the specific items included in the pilot study. Such a determination would provide the information necessary for decision-makers to choose what elements could be collected and what resolution of imagery would be required to do so.

Expected Benefits

This research is expected to help transportation agencies in inventory data collection by providing recommendations on the required resolution for specific features collected. This research is also expected to eliminate any hazard to data collection personnel as data is collected in house. As data is collected from remotely sensed images using a computer, the amount of time required and the number of personnel required are also expected to be less than the traditional methods of data collection. As accuracy of remotely sensed images is evaluated it is expected that the images provide the required accuracy for inventory data collection.

Thesis Organization

This thesis is organized into eight chapters. Chapter 1 introduces the reader to the need and objectives of the research. Chapter 2 provides a background of remote sensing and inventory data collection methods. The methodology followed in the pilot study is described in Chapter 3. Positional accuracy evaluation and results are presented in Chapter 4. Description of feature recognition and the results are provided in Chapter 5. The variation in location of features identified by different observers is described in Chapter 6. Accuracy of linear measurements and the results are presented in Chapter 7. Chapter 8 includes a summary of the thesis, conclusions, advantages and disadvantages of remote sensing, and recommendations. Detailed descriptions of the tests and results, which were not included in the chapters, are presented in Appendices A to D.

CHAPTER 2. BACKGROUND

This chapter provides a background on what data is collected by transportation agencies for inventory data and the methodologies of data collection used. Literature on remote sensing is also provided in this chapter so as to provide a background on how images are acquired and resolution of acquired images.

Remote Sensing

Remote sensing is the science and art of acquiring information about objects from measurements made at a distance, without coming into physical contact with the objects *(5)*. The USGS defines remote sensing as a process of detecting or monitoring an area, usually from the air or from space, by measuring reflected or emitted radiation *(6)*. Remote sensing typically consists of sensors mounted on a platform, which record the emitted, reflected and transmitted energy by an object on an image plane. The recoded value is the characteristic of the object and it can be used to identify it, based on a response signature recorded previously *(7)*.

There are many platforms available for remote sensing such as satellites, high altitude aircraft, low altitude aircraft, and ground observation platforms. The degree of response to the sensor depends on the intensity of the energy received, which in turn, depends on the distance of the sensor from the object.

Resolution is the ability of a sensor to distinguish two closely spaced objects as two rather than one object *(8)*. Resolution can also be defined as the closest distance between two distinguishable objects *(5)*. It is measured in lines per millimeter. There are two types of resolutions, ground resolution and photo resolution. The two resolutions are related by the term scale, which is defined as the ratio of distance on the map to the actual distance on the ground. The scale is calculated as:

Scale = f/H

Where,

f = principal distance from objective lens plane to film plane

H = flying height

For a fixed focal length, the scale varies based on the flying height. The greater the height, the larger the area covered, but with less resolution for the image. For digital images, resolution is measured in pixels. A pixel is the ground area corresponding to a single element of a digital image data set *(8)*. For example, in a 6-inch resolution digital image, each pixel corresponds to 36 square inches of ground area. The lower the flying height, the higher the scale of the image and lower the pixel size.

Aerial photographs require post processing to correct all the errors associated with them. Some of the errors that can occur stem from tilting of the camera axis, optical or photographic deficiencies, relief displacement effects and atmospheric effects. These errors result in height and tilt distortion, which produce inaccurate data. The field of photogrammetry deals with correction of these errors.

Satellite imagery has been available commercially for 20 years *(9)*. With the advent of the IKONOS satellite, multi spectral and infrared images at resolutions as low as 1 meter are now commercially available. This has reduces the cost of acquiring images while increasing the image acquisition frequency, as satellites pass the same area on earth based on its orbit and rotation speed.

There are many remote sensing applications in the fields of forestry, oceanography, geography, transportation, etc. Remote sensing has been used for planning, intersection studies, traffic studies, and inventory in transportation. Aerial photographs, videologs and photologs are some of the extensively used remote sensing technologies in transportation, especially for inventory purposes.

Aerial photographs were used for transportation studies as early as 1927 *(9)*. However the use of aerial photographs was minimal in these initial stages, as it required great deal of time and energy, because of lack of faster methods (computer packages) to complete data reduction and extraction. With the advent of digital or soft photogrammetry and high-resolution cameras, the process of data reduction and extraction became relatively easy. Aerial photographs are now used in route optimization and parking studies as well as density and level of service studies *(9)*.

Satellite images have been used for tracking roadways, extracting inventory data, and for traffic engineering studies *(9)*. Techniques for automated extraction of roadway inventory features, combined with high-resolution satellite imagery, were evaluated in a paper written by Karimi et. al. *(10)*. This current research evaluates the use, the accuracy of aerial photographs and simulated satellite images.

Roadway Inventory Data

Karimi et. al. *(2)* identifies roadway inventory data as those that are collected on a roadway or large sample of roadways that pertain to the roadway itself, not including adjacent buildings and areas, and that they relate principally to describing the identity, function, and physical features of the roadway and right-of-way (ROW). The following sections examine common inventory elements collected by states to meet both federal requirements and internal needs.

Highway Performance Monitoring System (HPMS)

The Highway Performance Monitoring System (HPMS), administered by the FHWA, specifies the minimum data to be collected by DOTs. HPMS data is collected, assembled, and reported to FHWA by state highway agencies, local governments, and metropolitan planning organizations. The HPMS covers all public roads including facilities both on and off state-owned highway systems *(3)*. The data items to be collected were identified by the FHWA and its partners, stakeholders and customers as those necessary for their individual needs, such as the apportionment of Federal-aid highway funds, analyses for Condition and Performance reports to Congress, and input for highway statistics and other FHWA publications.

The sheer extent of a State's roadway system precludes detailed, comprehensive inventories from being collected without significant resource expenditure. Consequently, the HPMS requires only certain basic inventory information to be reported for the entire street system (segment length, identification as a truck route, etc.). Other inventory items are reported only for subsets of roadways in the system. Two sampling methods are used for reporting these elements. The "Standard" sampling method gathers data from a statistically representative subset of major functional roads. Data include pavement surface type, lane width, speed limit, etc. "Donut Area" samples are required for areas in non-attainment for National Ambient Air Quality Standards (NAAQS), which use the HPMS to estimate Vehicle Miles Traveled (VMT) for air quality and conformity purposes *(3)*.

The HPMS requires a total of 98 data items to be collected. From those 98 elements, the following items were identified as physical inventory items. Other items were non-physical data such as volume, jurisdiction, etc.:

- Section Length
- Number of Through Lanes
- Surface/Pavement Type
- Lane Width
- Access Control
- Median Width, Type
- Shoulder Width – Right and Left, Type
- Parking
- Number of Right/Left Turn Lanes
- Number of Signalized Intersections
- Number of Stop Intersections
- Number of Other Intersections

Iowa Department of Transportation Data Needs

The Iowa DOT collects data for a number of purposes including establishing roadway mileage, updating maps, compiling statistics, locating physical features and for HPMS report preparation *(11)*. Collected data are used to determine what the present demands on the system are, as well as what they will be in the future. The following physical inventory items are collected by the Iowa DOT in addition to HPMS requirements *(12,13,14)*:

- Turning lane (type, presence)
- On-street parking (width, length)
- Traffic signal (structure, type, mast type)
- Adjacent land use (commercial, residential, etc.)
- Presence of rumble strips
- Curbing
- Critical intersection thru width
- Railroad crossings
    - Number of tracks
    - Intersections within 75 feet
    - Type of crossing protection

As was the case with the HPMS, the Iowa DOT collects quantity information for most segments rather than individual locations. For example, the total number of commercial driveways along a segment would be collected without accompanying information about where those driveways were located. As a result, if more specific data is desired, it must be collected separately, resulting in additional time and effort.

Data Needs at Other State DOTs

Other states, like Iowa, collect data other than that required by the HPMS. Karimi et. al. *(2)* summarized typical roadway inventory elements that are collected by State DOTs as shown in Table 2.1, information was obtained from a survey of DOTs.

Uses of Roadway Inventory Data

There are many applications in which inventory data are required. Information about traffic control devices such as signs, signals and pavement markings can be used for assessing adequacy and visibility, the need for upgrades, standards, analysis of accident causes, traffic safety and operations and planning of improvement programs *(1)*. Information about roadway features such as alignment, geometries, and railroad crossings can be used for determining equipment needs for roadway maintenance, analyzing impacts of design features on safety and operations, maintenance and rehabilitation of structures *(1)*.

Data about pavement condition such as surface condition and skid resistance can be used for analyzing pavement deterioration effects on safety and operations, evaluating pavement performance and subgrade design standards, optimizing the use of available funds, and preparing long-range budgets of transportation improvement plans *(15)*. Data about roadside features such as obstacles and safety hardware can be used for location identification and maintenance *(12,13,14)*.

Table 2.1: Common Roadway Elements Collected by DOTs

Administrative
Street names, route numbers
Truck restrictions
Roadway
Signs (message, size, support, reflectivity)
Signal timing
Pavement (marking, type, marking material, condition, friction)
Signal detectors
Lighting
Lanes (width, number, cross slope)
Shoulders (width, material, cross slope)
Roadside hazard rating
Curb or sidewalk (type, material, lateral placement)
Horizontal curve radius, length, median width
Vertical curve length, grade
Median type
Parking lane, gutter, or sidewalk width
Parking restrictions
Sight distance
Traffic
Volume (hourly, directional, daily)
Posted speed limits
Volume by weight and class
Seasonal or monthly volume factors
Safe curve speeds
Mean, percentile, and free-flow speeds
Other
Driveway, median opening width
Driveway grade
Adjacent land use
Utility wire clearance
RR, crossing, angle, number of tracks, control
Interchange median opening design
Bridge (width, length, clearance, design)
Structural quality
Drainage features

Inventory Data Collection Methods

Several methods are commonly used for the collection of inventory data. The different methods vary in terms of cost and the types of data that can be collected. Many transportation agencies in the United States are collecting data either manually or by using videolog vans *(11)*. A description of each of the different methods is provided in the following sections.

Manual Data Collection

Manual data collection, as the name implies, requires that personnel physically measure or count inventory elements in the field. Measuring devices (i.e. a distance measuring wheel) are used to obtain the desired information, such as lane width. Recording devices (pen and paper, laptop computer, etc.) are used to record count information, such as number of lanes or number of driveways per mile. Manual methods are the simplest of all data collection methodologies, but their limitation is that they can only be implemented for small and medium sized systems, or where other methods of data collection are not feasible. These methods require minimum equipment for collecting data but are labor intensive *(1)*. As such, manual data collection is usually implemented on rural primary roads and municipal roads *(11)*. Data are collected by visiting the site and recording the inventory information. Although discussed in a following section, manual data collection may include the use of global positioning systems (GPS).

Manual data collection is most often employed when other methods are not practically available, since they can be labor intensive. The following is a listing of advantages, disadvantages, and the type of data that manual data collection, not including GPS, is best suited for:

Advantages

- Highly trained personnel are not required
- Precise length measurements can be made
- Low equipment costs
- Allows firsthand visual inspection of roadway features

Disadvantages

- Difficult to record spatial location
- Time consuming
- Data collectors may be located on or near hazardous roadways
- May be distracting to motorists

Suitable for

- Identification of elements (pavement type, presence of turning lanes, etc.)
- Linear measurements (driveway width, etc.)

Not suitable for

- Spatial location
- Extensive linear measurements such as segment length

Global Positioning Systems

The widespread availability of GPS technology in recent years has fundamentally altered the way spatial data can be collected. A GPS receiver captures signals from a global constellation of GPS satellites. With at least four satellites, a GPS is able to calculate its distance from each satellite and through triangulation, determine its position on earth. Consequently, a GPS can fairly accurately locate and store planar coordinates (usually latitude and longitude) for a particular point. Related attribute data can be both manually or digitally data-logged and then attached to a point feature in a database. Line and polygon features may also be collected with a GPS by relating a line or series of lines between two or more points. The portability and ease of use characteristics of GPS allows collection of spatial data in a context not previously realized. With GPS, the collection of positional information at locations where it may be difficult or even dangerous to collect such data with traditional surveying equipment is now possible. The technology also allows collection of real time data.

There are hundreds of commercially available GPS units in the market. Such units range in price from a few hundred dollars for low-accuracy recreational units to surveying-quality receivers, which cost several thousands of dollars. GPS receivers are designed for numerous uses, including marine, aircraft, and land use, and can come in a variety of forms, including Personal Computer Memory Card International Association (PCMCIA) cards, handheld computers, and 'black-box' sensors

The many options available can make it difficult to select a GPS receiver and antenna that best meet application needs while optimizing cost, accuracy, and other desired features. However, accuracy ranges tend to fall into three distinct groups: low-end receivers with 100 meter 'plus' accuracy levels (available for $200 to $500), mid-range receivers with one to ten meter-level accuracy (in the $2000 to $5000 price range), and high-end receivers with centimeter or millimeter-level accuracy (often with prices exceeding $10,000).

Global positioning systems are powerful tools for collecting data for use with Geographic Information Systems (GIS) *(16)*. Data collection efforts using a GPS typically require more data collection time than traditional data collection methods, but the data can be easily be converted to a compatible GIS format and then stored, maintained, and analyzed with the GIS. The following is a listing of advantages, disadvantages, and the type of data that GPS data collection is best suited for:

Advantages

- A high level of spatial accuracy can be achieved
- Elevation can be included as well as planar coordinates
- If lower accuracies are acceptable, handheld GPS are fairly inexpensive
- Can be combined with other data collection methods (manual methods)

Disadvantages

- Time consuming
- Labor intensive
- Data collectors may be located on or near hazardous roadways
- May be distracting to motorists
- Equipment for higher accuracy may be costly

Suitable for

- Features where spatial location is important

Not suitable for

- Condition assessment

Videolog/Photolog

Video and photologging provide a visual record of the roadway and its surrounding environment. Both utilize a vehicle, which drives along the roadway as the recording devices gather data and produce a visual record, which can be referenced at a later date. The main difference between the two methods is the recording medium: video versus pictures. The videolog storage medium can be reused. Many videologging vehicles also use GPS and/or distance measuring instruments so that a variety of data can be collected *(2)*.

In terms of labor, video and photo logging are less labor intensive than manual collection methods. Generally, only one or two personnel are required to perform the data collection. One advantage is that data collectors are not directly exposed to traffic, as they ride inside the vehicle with the recording instruments. However data collection is still performed on-site and may interfere with normal traffic operations. The following is a listing of advantages, disadvantages, and the type of data that video/photolog data collection is best suited for:

Advantages

- Can be combined with other types of data collection such as GPS or Distance Measuring Instrument (DMI)
- Can be collected fairly rapidly

- Data collectors do not have to physically locate on roadways
- Allows visual inspection of roadway features

Disadvantages

- Data collection vehicles may interfere with motorists
- Still may be time consuming as each road segment must be physically driven to collect data

Suitable for

- Condition assessment
- Spatial location when combined with GPS
- Linear measurement such as segment length when combined with GPS or DMI

Not suitable for

- Short linear measurements such as driveway width
- Spatial location without GPS
- Linear measurements without GPS or DMI

Aerial Photographs

Aerial photography has also been used for the collection of roadway inventory data, but not to a great extent. Images taken from an aircraft allow a planar view of the road network as well as surrounding land use, including the location of structures. Aerial photos have the advantage of displaying an entire area for analysis. Such a display provides a better picture of how the transportation network interacts with its environment.

However, the analysis and interpretation of images requires a great deal of skill. Additionally, good weather is required in order for a flight to take place and produce the required imagery. This limits the available window in which work can be completed. Some elements, such as signs, may not be visible at all in some resolutions. Image processing takes time, and it can also be quite expensive. The storage of the processed images can also become an issue, as the images produced by a number of flights can take up a large amount of space (either in print or electronic form) and also the resolution affects the storage space required.

CHAPTER 3. PILOT STUDY

The pilot study for this project was along the US-69 corridor in the city of Ames, Iowa as shown in Figure 3.1. The study corridor included three roadway segments, South Duff Avenue, Lincoln Way and Grand Avenue. The length of the corridor segment was 4.1 miles and most of the surrounding land use was either commercial or residential. The corridor was selected in part due to the availability of aerial images at different resolutions along it. In addition, a wide variety of inventory elements were present along the corridor. Eight intersections located in the corridor were included in the analysis. Two intersections off-corridor were also included in the pilot study since imagery was available for them as well and as less number of intersections were present for linear accuracy evaluation along the corridor.

Description of Image Datasets

Four aerial photograph datasets of varying resolutions were available for the study area and utilized in different aspects of the research. All datasets were panchromatic. The imagery datasets included:

<u>1-Meter Resolution Dataset</u>

A 1-meter resolution dataset was available from the Iowa State University Geographic Information Systems Support and Research Facility. The original source of the images was the USGS DOQQs. The images were taken in 1994 by the Western Mapping Center (WMC) and stored in Tagged-Image File (TIF) format.

The 1-meter images are similar to the resolution available from the IKONOS satellite. As such, these images were used to simulate what was most recently available from satellite data.

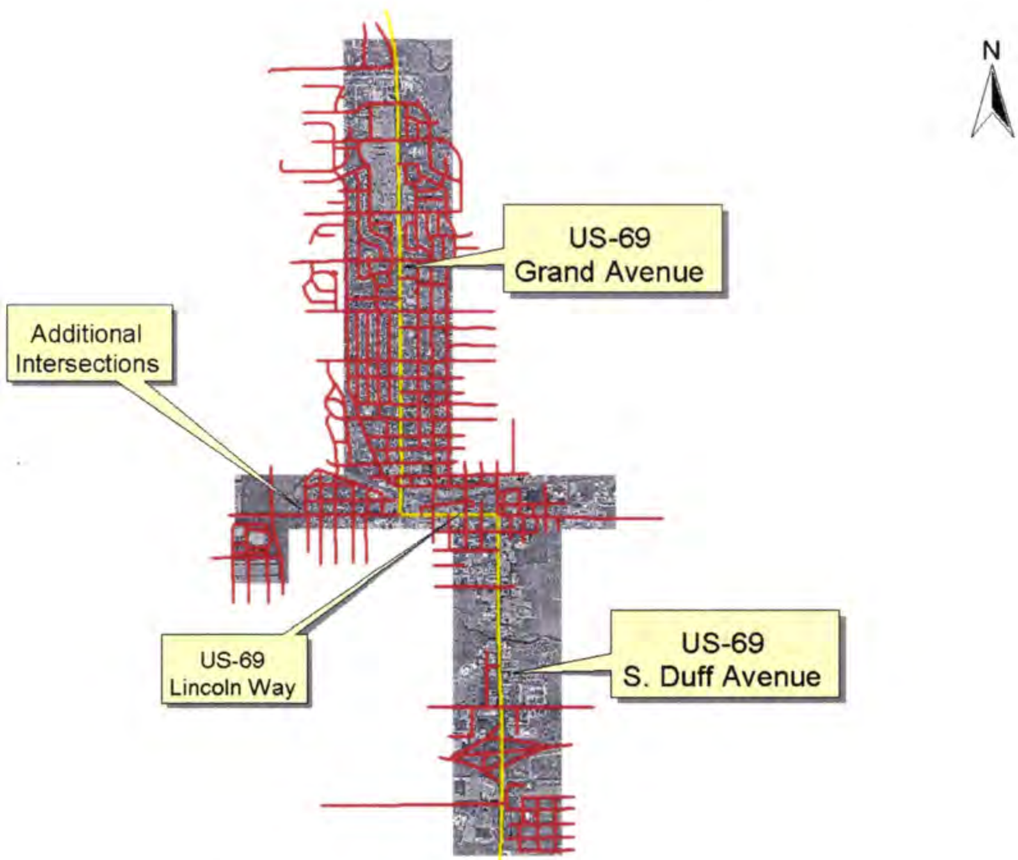


Figure 3.1: US-69 pilot study area corridor

24-Inch Resolution Dataset

The 24-inch ortho-rectified dataset was obtained from the Story County Planning and Zoning Department, Story County, Iowa. The original photographs were taken in 1998, by a consulting company, Aerial Services, Incorporated. The images were available in a digital format and stored in Multi-resolution Seamless Image Database (MrSID) format.

6-Inch Dataset

A digital dataset with 6-inch resolution was available from the Iowa Department of Transportation. These images were originally obtained by the DOT from Story County Planning and Zoning Department, Story County, Iowa. The images were also from 1998 and were taken by Aerial Services, Inc. The 6-inch dataset was ortho-rectified, and stored in Tagged-Image File (TIF) format.

2-Inch Dataset

The 2-inch dataset was derived from photographs available from the photogrammetric division of the Iowa DOT. The original photos were taken in the spring of 1999 by a commercial vendor for the Iowa Department of Transportation. The negatives of the photographs were scanned using a commercial vendor, Atlantic Technologies, at 0.177-foot resolution and then georeferenced. This process began by converting the file format of the scanned images from compressed jpeg format to tiff format. Next, the image size was reduced by trimming the sides of each image using ERDAS Imagine, as the sides contain borders, which does not allow proper overlap of each image. Each image was georeferenced using at least 4 control points. The georeferenced images were then opened in ArcView Image Analysis and saved as new tiff images. This was done so as to use the images directly in ArcView, which is capable of building pyramid layer files (.rrd files) for all saved images. Pyramid layer files are created by image analysis software's, which store the image file attributes such as band information in a compressed file (,rrd file) for faster display of images when magnified or reduced form original size. The pyramid layer files created by ERDAS Imagine do not produce compatible pyramid layer information for use in ArcView.

Inventorying methodology

Data elements used

A list of inventory elements tested in this research is shown in Table 3.1. The data elements were selected based on those currently collected by the Iowa Department of Transportation and those required for collection by the HPMS. In order to be included in the list, several occurrences of a specific inventory element in the study area were necessary. For example, several railroad crossings would have to be present before the location of railroad crossings was used as a data element. A description of the data elements required by HPMS and collected by the Iowa DOT was described in Chapter 2.

Table 3.1: Transportation Inventory Data Elements included in pilot study

Data Element	Data Element	Data Element
Through lanes Number Width	**Medians** Presence of median Median type Width	**Right turn lane** Presence Number Width
Intersection Number Design	**Shoulder** Presence Type Width	**Left turn lane** Presence Number Width Length
Presence of crosswalks	**Location of stop bars**	**Presence of pedestrian islands**
Access Private access Commercial/ industrial access	**Signal** Structure Type Location	**On-street parking** Presence
Pavement type	**Land use**	**Total roadway width**
Signs Presence Location	**Railroad crossings** Number Location Number of tracks	**Bridges** Number Location Width & Length

Data Extraction

Inventory elements selected for use in the pilot study were identified, measured, and located in each dataset using ArcView GIS version 3.2. The collection of data was primarily accomplished using manual digitization of features present in the software. Elements were identified manually and attributes of the elements, such as coordinates, were populated in an attribute table using ArcView Avenue scripts. Also, each element required a standardized procedure for identification. The particular technique for the identification and measurement of each element is presented in Table 3.2. Figures 3.2 and 3.3 illustrate the process. Table A.1 in Appendix A describes whether a feature can be seen on a particular resolution aerial photograph or not. The table also describes up to which resolution of aerial photographs a feature can be identified.

Table 3.2: Rules for Element Identification and Measurement

Data Element	Description of collection technique	Data Element	Description of collection technique
Number of Through Lanes	Identifier: Pavement marking; Position of Vehicle	Land Use	Identifiers: Presence of parking; Driveway locations/spacing; Surrounding land use
Through Lane Width	Measured from roadway edge line to inside lane marking or centerline	Crosswalks	Identifiers: Pavement marking
Shoulder Presence/Type	Main Identifier - Color differences between pavement and shoulder material	Pedestrian Islands	Identifiers: Sidewalks and vegetation within an intersection
Shoulder Width	Measured from edge of pavement to edge of vegetation	Stop Bars	Identifiers: Pavement marking
Parking Presence/Type	Identifier: Vehicle position along roadway; Pavement markings	Signal Structure/Type	Identifier: Structure overhanging roadway; Signal heads
Median Presence/Type	Identifier: Color differences from roadway; Object markers	Right Turn Lane Presence	Identifiers: Roadway Geometry; Pavement Markings
Median Width	Measurement made from one identified edge of median to the opposite edge	Right Turn Lane Length	Measurement made from stop bar to end of solid turn lane marking
Private Access	Total number of private drives within 250 feet (either side) of the intersection; drives identified by surface color and land use	Right Turn Lane Width	Measurement made from roadway edge line to solid turn lane marking
Commercial/ Industrial Access	Total number of commercial and industrial drives within 250 (either side) of the intersection; Drives identified by surface color and apparent land use	Left Turn Lane Presence	Identifiers: Roadway Geometry; Pavement Markings
Pavement Type	Identifier: pavement coloration; Type of cracking present if visible	Left Turn Lane Length	Measurement made from stop bar to end of solid turn lane marking
Intersection Design	Identifier: Layout of the intersection	Left Turn Lane Width	Measurement made from roadway centerline or median to solid turn lane marking
Signs	Identifier: Shadow; shape	Railroad Crossings	Identifier: Presence of tracks, gates; Intersecting with roadway
Bridges Presence/ Length	Identifier: pavement coloration; railings on sides. Measured from end to end of railings	Total Roadway Width	Measurements made from roadway edge marking to opposite edge marking or curb to opposite curb

Figure 3.2: Feature identification in ArcView 3.2

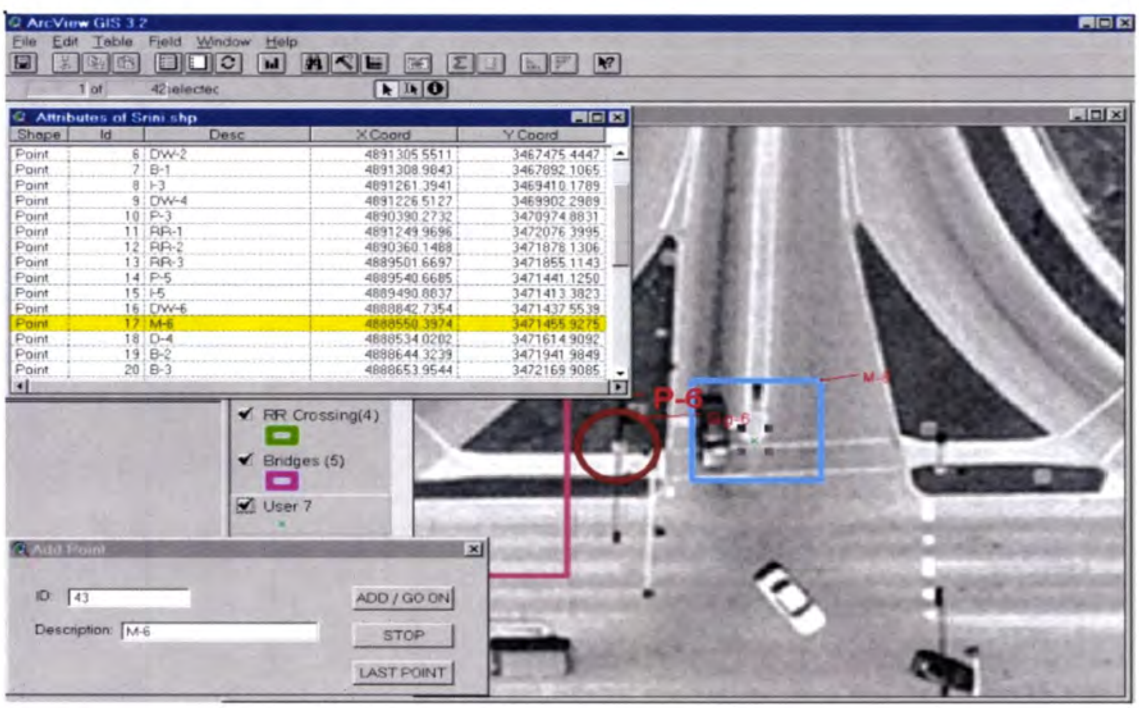


Figure 3.3: Updating attributes in ArcView 3.2

Data collection consisted of the following:

- Appropriate databases were created to store recorded information;
- The presence of a specific feature was identified by visually examining the imagery (i.e. the presence of a stop sign);
- Non spatial information about the feature was recorded in the database (i.e. number of lanes for the through lanes);
- Spatial location was identified and coordinates recorded (if appropriate) using an ArcView Avenue script (i.e. spatial location of the center of a driveway or location of a drainage box)
- Linear measurements were made (if appropriate) using the distance measuring tool within ArcView and recorded into a database.

In the course of work, it was noted that significant changes had occurred at several intersections after the 1-meter images (earliest dataset) were taken. Changes included new geometric features, significant changes in land use, etc. Consequently, intersections and locations where changes were evident were not included in the study. This resulted in loss of four intersections in the 1-meter dataset, leaving a smaller sample size. Other datasets were more recent and represented current on-road conditions, with the possible exception of the fading or restriping of pavement markings. Therefore, the reader should take note that all analysis done for 1-meter images is from a limited sample compared to that of the three remaining datasets.

CHAPTER 4. POSITIONAL ACCURACY

Positional accuracy is how closely the coordinate descriptions of objects in particular spatial dataset compare to their actual location *(17)*. A variety of factors influence the positional accuracy of digital geospatial data. Errors can be introduced by digitizing methods, source material, the specifications of aerial photography such as resolution and number of bands, aerotriangulation technique, ground control reliability, photogrammetric characteristics, resolution and processing algorithms *(17)*. Individual errors from these sources may not be significant, but collectively they may significantly affect data accuracy. If positional accuracy is not accurate, then data extracted from that source will produce erroneous results leading to waste of resources *(17)*. As data sets from different sources may be required to be combined for many applications, it is required that positional accuracy is specified for each data set and their accuracies match each other. If positional accuracies of data sets to be combined do not match, then the results produced from those data will not be accurate even if one data set has highly accurate positional accuracy. For example, signs may appear within private property, if land use data and GPS data of signs are combined and the accuracy of land use data does not match the accuracy of GPS data, which leads to erroneous inventory data. Therefore, it is suggested that any geographic data be tested for its positional accuracy before the data is actually used for any application *(18)*. The National Standard for Spatial Data Accuracy (NSSDA) provide a method for estimating positional accuracy of digital geographic data. The national standards and the tests are explained in the following sections.

National Standards for Spatial Data Accuracy

The National Standard for Spatial Data Accuracy developed a statistical testing methodology for estimating the positional accuracy of digital geospatial data with respect to georeferenced ground positions of higher accuracy *(18)*. This test applies to any georeferenced digital geospatial data in raster, point or vector format, which are derived from sources such as aerial photographs, satellite imagery and ground surveys. A data set's accuracy is evaluated by comparing the coordinates of several points, which can easily be located in both the test and independent data sets of greater accuracy. Well-defined points must be used for comparison. Features like utility access covers, intersections of sidewalks, curbs or gutters make suitable test points *(17)*. The independent data set of higher accuracy can be any data set whose accuracy is predefined, such as GPS survey or geodetic control survey.

Twenty or more test points are required to conduct a statistically significant accuracy evaluation, regardless of the size of the data set or area of coverage *(17)*. The standard does not provide any threshold accuracy values, but will only report the accuracy of the data set. The resulting positional accuracy should be reported in the same units as that of the source data set, which allows for comparison of different resolutions.

No national standards exist for the positional accuracy of roadway point features. The required accuracy for locating point features is dependent on the application. For example, location of signs may have lower accuracy requirements than accident locations. NCHRP 430 *(19)* suggests the following spatial accuracy for point roadway features to support highway safety design decisions:

- Fixed objects such as signs, utility poles, light poles, etc: ± 3.28 feet
- Location of drainage structures: ± 0.33 feet
- Center of intersection: ± 3.28 feet
- Location of intersection of roadway and railroad crossings: ± 3.28 feet

RMSE Test and NSSDA

The Federal Geographic Data Committee recommends that any geospatial data be tested for horizontal and vertical positional accuracy. These accuracies are tested using Root Mean Square Error (RMSE) test and the NSSDA. The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points *(18)*. This test is performed both in X and Y directions in the horizontal plane for horizontal accuracy. The equations used for RMSE calculations are,

$$\mathrm{RMSE}_x = \sqrt{\frac{\sum\left(X_{\mathrm{data,i}} - X_{\mathrm{check,i}}\right)^2}{n}}$$

$$\mathrm{RMSE}_y = \sqrt{\frac{\sum\left(Y_{\mathrm{data,i}} - Y_{\mathrm{check,i}}\right)^2}{n}}$$

Where: $x_{data,i}$, $y_{data,i}$: are the coordinates of the i^{th} check point in the dataset

$x_{check,i}$, $y_{check,i}$: are the coordinates of the i^{th} check point in the independent source of higher accuracy

n : is the number of check points tested

i : is an integer ranging from 1 to n

Vertical accuracy is calculated by performing an RMSE test in the Z direction. If the RMSE is assumed to be the same in X and Y directions then the total RMSE is calculated based on the following equation.

$$\mathbf{RMSE_r} = \sqrt{RMSE_x^2 + RMSE_y^2}$$

Any variation in the data set such as uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the data set are taken into account by the NSSDA value. The NSSDA value is the 95% confidence value of the accuracy, which is calculated using the equation,

$$\text{NSSDA} = \text{Accuracy}_r = 1.738 * \text{RMSE}_r$$

The Circular Map Accuracy Standards (CMAS) calculates the 90% confidence percentage, using the equation *(18)*

$$\text{CMAS} = 1.5175 * \text{RMSE}_r$$

Accuracy Evaluation of Pilot Study Datasets

The 2-inch, 6-inch, 24-inch and 1-meter resolution aerial photographs were tested for positional accuracy in the horizontal direction. The methodology and results are described in the following sections.

Methodology

Two sets of features that could be represented as points and could reasonably be seen in all four datasets were selected to compare positional accuracy. The selected features were the southeast corner of two intersecting sidewalks and the southeast corner of drainage structures, as shown in Figure 4.1. A set of 55 points was located, if possible, in each of the four datasets using ArcView and coordinates added as attributes using Avenue scripts. The points were located using the same coordinate system and datum as for the reference GPS points described below.

For the 6-inch dataset all 55 points were located and matched. In the 24-inch dataset only 37 of the 55 points were discernible enough to be located. In the 1-meter aerial photographs, only 25 points could be identified sufficiently to locate coordinates. Since the 2-inch dataset was initially only a set of scanned images, 29 of the GPS points had to be used to georeference the images. This left only 26 points that could be used to test positional accuracy.

(a) Intersection of side walks (b) Drainage structure

Figure 4.1: Southeast corners of features used for comparison

Reference Points from Real Time Kinematic GPS

To provide an independent dataset of higher accuracy, a Kinematic GPS survey was contracted for with an independent engineering consulting firm to obtain planimetric coordinates for the 55 selected points. The survey was performed using a Real Time Kinematic GPS unit, with a horizontal accuracy of 0.5 cm and vertical accuracy of 2 cm. The coordinates were obtained in State Plane Iowa North coordinates system and NAD 1983 datum. The list of coordinate values for 55 points collected is presented in Appendix A. The time taken for the data collection was also recorded for time and cost comparisons, which are presented in chapter 8.

In order to correct the GPS points collected, the Kinematic method used a static survey system at one station (master) while another survey system (rover) moved from one station to the next until all locations were mapped. For each point collected, the rover occupied the position for 2 to 10 minutes. During the entire data collection session, both receivers continuously tracked the same satellites. Unlike differential GPS, where coordinate corrections are determined, the Kinematic method uses a phase difference technique to determine the intersecting vectors. RTK systems can achieve sub-centimeter accuracy, free of cycle slips using four or more satellites *(20)*. Figure 4.2 shows data collection using the RTK system with the master station and rover.

Positional Accuracy

The GPS points were referenced with a unique id and matched to their corresponding point located in each of the four datasets. RMSE and NSSDA tests were

(a) Rover on a control point (b) Main receiver on base station

Figure 4.2: RTK GPS unit with master and rover units.

then performed for each of the four datasets, resulting in a measure of the error associated for each dataset. The complete calculations and results of the RMSE and NSSDA tests are provided in Appendix B. A sample calculation is shown in Table 4.1.

Results

Table 4.2 summarizes the results of RMSE and NSSDA tests for all the four datasets. The values are the 95% confidence percentages, which means that 95% of the time the data points were within the NSSDA value of its location as defined by kinematic GPS. For example, the horizontal location of any well-defined feature in 6-inch resolution will be within 3.89 feet of its true location, 95% of the time.

Table 4.1: Positional Accuracy for 2-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+
		GPS	2 Inch aerial			GPS	2 Inch aerial			(Diff in Y)^2
1	(D) Airport Road, Near to Sams club Parking Lot	4890581.180	4890579.402	1.778	3.160	3463500.760	3463500.708	0.052	0.003	3.163
6	(D) S. 16th Street West, Away from the X	4892018.840	4892017.990	0.850	0.722	3466132.550	3466131.691	0.859	0.738	1.461
7	(D) Near to K-Mart Parking Lot on Buckeye	4890955.890	4890955.810	0.080	0.006	3466790.710	3466790.659	0.051	0.003	0.009
8	(D) On Buckeye, to the end, near Red Lobster	4890951.020	4890949.857	1.163	1.353	3467603.500	3467603.472	0.028	0.001	1.354
17	(D) Lincoln Way & Grand Ave, Near H-Video	4888629.180	4888629.038	0.142	0.020	3471477.110	3471477.050	0.060	0.004	0.024
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888468.169	0.191	0.036	3471472.060	3471471.572	0.488	0.239	0.275
21	(S) Wilson Ave & 8th St	4889064.870	4889064.693	0.177	0.031	3473614.390	3473614.933	-0.543	0.295	0.326
22	(S) Hodge Ave & 8th St	4888238.080	4888238.258	-0.178	0.032	3473592.320	3473591.994	0.326	0.106	0.138
23	(S) Grand Ave & 9th St	4888539.530	4888539.675	-0.145	0.021	3474108.680	3474108.690	-0.010	0.000	0.021
24	(S) Grand Ave & 11th St	4888589.330	4888590.055	-0.725	0.526	3474738.240	3474739.537	-1.296	1.681	2.207
26	(S) Harding Ave & 13th St	4888267.510	4888266.998	0.512	0.263	3475689.900	3475688.399	1.501	2.252	2.515
27	(S) Wilson Ave & 16th St	4889021.470	4889020.263	1.207	1.458	3477059.490	3477058.216	1.274	1.622	3.080
28	(S) Harding Ave & 16th St	4888265.630	4888266.211	-0.581	0.338	3477008.060	3477008.783	-0.723	0.522	0.860
29	(S) Duff Ave & Jenson Ave	4889025.730	4889024.950	0.780	0.608	3481760.110	3481759.982	0.128	0.016	0.624
30	(S) Bus Stop near Wal-Mart parking lot	4888317.410	4888318.065	-0.655	0.429	3481754.210	3481754.101	0.109	0.012	0.441
31	(A) Access road on 28th St, next to Grand Ave	4888603.690	4888604.460	-0.770	0.592	3481036.940	3481037.361	-0.421	0.177	0.769
32	(S) 30th St & Ferndale Ave	4887439.790	4887439.566	0.224	0.050	3481673.140	3481673.097	0.043	0.002	0.052
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884890.212	0.108	0.012	3470796.820	3470796.590	0.230	0.053	0.065
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886731.781	0.189	0.036	3471371.320	3471371.320	0.000	0.000	0.036
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886824.187	0.293	0.086	3471432.490	3471432.479	0.012	0.000	0.086
36	(A) Access road from house to Lincoln Way	4886492.020	4886492.664	-0.644	0.415	3471365.000	3471365.123	-0.123	0.015	0.430

Table 4.1: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)^2
		GPS	2 Inch aerial			GPS	2 Inch aerial			
38	(D) S. 5th St, next to Pizza Hut	4891370.670	4891370.725	-0.055	0.003	3469430.490	3469432.067	-1.577	2.486	2.489
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890347.275	0.355	0.126	3470915.720	3470914.907	0.813	0.661	0.787
42	(D) Grand Ave & 7th St	4888541.310	4888541.346	-0.036	0.001	3473225.620	3473225.805	-0.184	0.034	0.035
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887878.069	0.491	0.241	3477403.660	3477404.718	-1.058	1.119	1.360
55	(D) On Access road to Hilton Coliseum	4885153.290	4885153.318	-0.028	0.001	3470286.340	3470286.373	-0.033	0.001	0.002

Sum	22.608	ft
Average	0.870	ft
RMSE	0.932	ft
NSSDA	1.614	ft

D = Drainage Structure

A = Access Road

S = Side Walk intersection

Notes:
A circle of 0.93 ft radius defines horizontal RMSE
Positional Accuracy: Tested 1.61 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 1.61 ft of its true location, as best as its true location has been determined 95% of the time.)

Even in the 1-meter datasets, 95% of points were located within 10.84 feet of their true location. This accuracy may be sufficient for a number of applications such as sign location, provided they can be extracted as explained in chapter 5.

Table 4.3 summarizes the results of RMSE and Circular Map Accuracy Standards (CMAS) for all four datasets. The CMAS values are 90% confidence percentages, which means that 90% of the time the data points were within the CMAS value of their location as defined by kinematic GPS. The CMAS values are computed, as some applications require 90% confidence percentages.

Table 4.2: RMSE and NSSDA values for each dataset

Aerial Resolution	RMSE (In feet)	NSSDA (In feet)
2-inch	0.93	1.61
6-inch	2.25	3.89
24-inch	3.04	5.26
1-meter	6.26	10.84

Table 4.3: RMSE and CMAS values for each dataset

Aerial Resolution	RMSE (In feet)	CMAS (In feet)
2-inch	0.93	1.41
6-inch	2.25	3.41
24-inch	3.04	4.61
1-meter	6.26	9.50

CHAPTER 5. FEATURE RECOGNITION

Inventory data collected from aerial photographs should be consistent and accurate. All the features present on the ground should be recognizable on an aerial or satellite image to be useful for inventorying purposes. If only a limited number of all features present can be recognized at a particular resolution, then images of that resolution may not be useful for inventorying purposes. Feature recognition, termed as Identification Percentage (IP), is a measure of the recognizability of features in remotely sensed images. It is the percentage of features that can be extracted from images out of the total number of features present on the ground. For example, an IP of 95% for traffic signals at 6-inch resolution means that 95% of the total number of signals present on the ground can be recognized. If this percentage is acceptable for inventory purposes, then an image at that resolution can be used to inventory features. The methodology followed to compute identification percentage and the results obtained are described in the following sections of this chapter.

Methodology

Feature recognition is a measure of whether a particular inventory feature can be identified at all and whether it can be identified consistently. For example, it is a measure of how many stop signs can be seen and identified on an image. The percentage of elements, which can be identified in all resolutions of images, is obtained using IP. The IP was computed as:

$$IP (\%) = (F_a/F_g) * 100$$

Where:

F_a = number of features identified in photos

F_g = number features identified in the field

Manual photo interpretation was used for feature recognition in this research. Photo interpretation is the process of identifying features on an image. This is achieved by distinguishing features from its surroundings. Therefore features can be interpreted easily in a high resolution images than a low resolution images, as in low resolution images distinction between the features and the surroundings decreases. All the four data sets, 2-inch, 6-inch, 24-inch and 1-meter, were used to get the IP at each resolution.

Features were first identified on aerial photographs and encircled using the ArcView polygon tool. In many cases features could be directly identified. For example, through and turn lanes, medians, signals etc. This was especially true for the higher resolution datasets. For those features, which cannot be easily identified on the images, photo interpretation was used. For example, a drainage box may be identified based on its shape (a distinct rectangle), color (white or light gray), and location (along the side of a road). Images containing the identified features were then printed and taken to the field for validation. Any feature, which was present on the ground and could not be identified on the aerial photographs, were marked on these printed images. For features where large numbers of elements, such as signs, were present along the corridor, samples were counted on segments of roadway. Sample sizes for particular inventory elements were not consistent across datasets. The 2-inch dataset covered slightly less area than the other datasets, which may have also influenced sample size. Additionally geometric changes in the roadway had occurred at several locations between the dates that the 1-meter photos were taken and the time of field data collection. Such locations were eliminated from study, resulting in fewer samples. As shown in Table 5.1, most features could be consistently identified in the 2-inch and 6-inch datasets. It is also noted that identification percentage may be greater then 100%, if the features are over estimated.

One drawback to aerial photographs is that features may be obstructed by vegetation, thereby resulting in an underestimation of the identification percentage. For example, in a 6-inch resolution aerial photograph, 2 signals were undetected as they were obstructed by vegetation and could not be identified. Figure 5.1 depicts this scenario. The IP for signals in 2-inch resolution was 95%, because of vegetation obstruction, which is not the true IP for signals in that resolution. Therefore, the identification percentage for signals was recalculated without considering the obstructed signals.

Another drawback of aerial photographs is that some inventory such as on street parking requires that vehicles be parked on street at the time aerial photograph is taken. Figure 5.2 shows designated on street parking spaces, but because there were no parked vehicles at the time aerial photograph was taken, its identification percentage was underestimated.

Results

Identification results are presented in Table 5.1. Some features are grouped together to reduce the number of entries in the table. Features that are grouped are signs,

Figure 5.1: Underestimation of signals due to vegetation cover

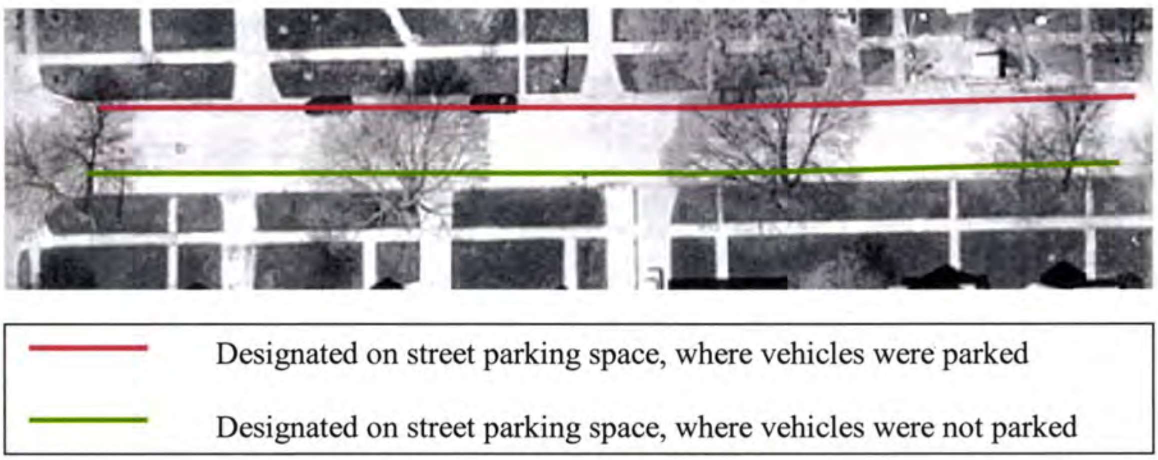


Figure 5.2: Underestimation of on street parking inventory

which include stop signs, speed limit signs, and informatory signs; driveways which include commercial and residential driveways; number of separations which include overpasses and underpasses; and bridges which include roadway and railroad bridges.

It is observed from Table 5.1 that most of the features can be extracted from higher resolution images such as 2-inch and 6-inch. As resolution decreases the IP also decreases as manual photo interpretation is used for identifying features in lower

Table 5.1: Feature Recognition, Identification Percentage (IP)

Feature	2 inch			6 inch			24 inch			1m (simulated satellite)		
	Photo	Ground	IP (%)	Photo	Ground	IP (%)	Photo	Ground	IP (%)	Photo	Ground	IP (%)
Signs	65	68	96	33	68	49	0	68	0	0	68	0
Signals	44	44	100	42	42	100	0	44	0	0	44	0
Number of Intersections	20	20	100	22	22	100	22	22	100	22	22	100
Intersection Geometric Design	10	10	100	10	10	100	10	10	100	6	6	100
Intersection Land use	10	10	100	10	10	100	10	10	100	6	6	100
Number of Lanes between Intersections	47	47	100	47	47	100	28	47	60	44	47	94
Number of Right Turn Lanes	13	13	100	13	13	100	7	13	54	4	7	57
Number of Left Turn Lanes	20	20	100	20	20	100	12	20	60	3	9	33
Number of Railroad Crossings	4	4	100	4	4	100	4	4	100	4	4	100
Number of Railroad Tracks at crossings	7	7	100	7	7	100	7	7	100	7	7	100
Number of Driveways	155	155	100	159	155	103	112	155	72	49	80	61
Number of bicycle lanes/sidewalks	36	36	100	41	41	100	37	41	90	12	41	29
Medians	9	9	100	9	9	100	5	9	56	4	6	67
Median Type	9	9	100	7	9	78	1	9	11	0	6	0
Pavement Type	19	20	95	11	20	55	0	20	0	0	12	0
Number of TWLTL	1	1	100	1	1	100	0	1	0	0	1	0
Number of separations	3	3	100	3	3	100	3	3	100	3	3	100
Bridges	5	5	100	5	5	100	5	5	100	5	5	100
Pedestrian Crossings	16	16	100	16	16	100	0	16	0	0	16	0
Pedestrian Islands	3	3	100	3	3	100	1	3	33	1	3	33
Stop Bars	20	20	100	16	20	80	0	20	0	0	12	0
On Street Parking Presence	19	20	95	19	20	95	11	20	55	12	20	60
Drainage Structures	14	14	100	14	14	100	0	14	0	0	14	0
Shoulders	2	2	100	2	2	100	0	2	0	n/a	n/a	n/a
Utility Poles	147	147	100	113	147	77	33	147	22	0	147	0

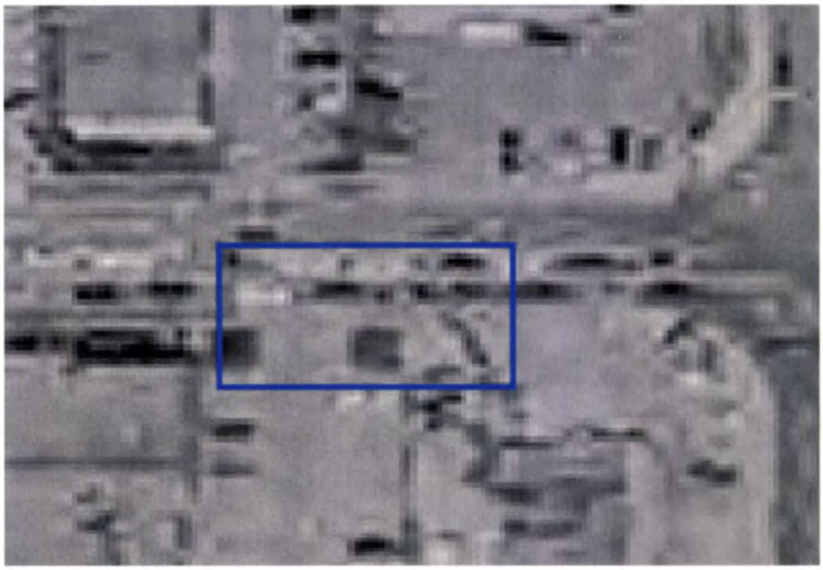
Notes: (IP > 100% indicates the feature was overestimated); ■ ≥ 95% ■ ≥ 85% and < 95% ■ < 85% ■ > 100%

resolutions. Features such as on street parking should not be collected from the images, as they can produce varying results depending on the time when the images were taken. As observed in Table 5.1, even in 2-inch resolution only 95% of the on street parking inventory can be obtained as no vehicle was parked in one of the designated parking space.

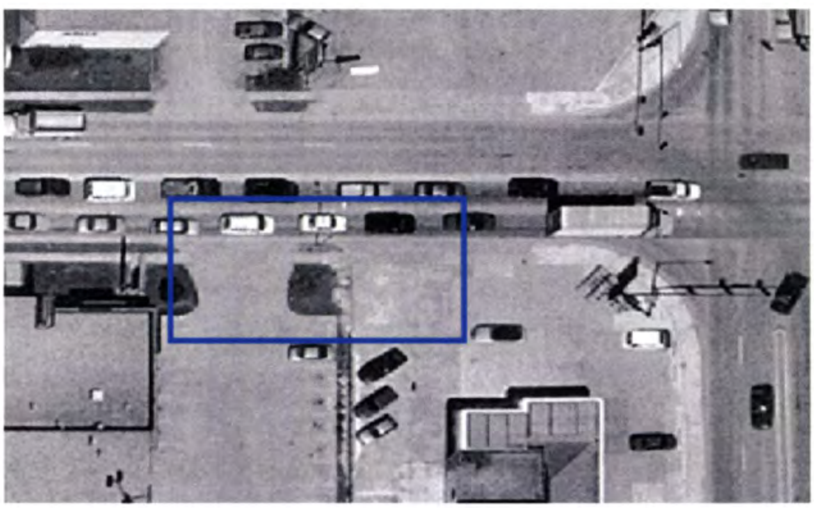
In the absence of pavement markings or where pavement markings were not discernable, the number of traffic lanes were identified based on traffic movement. This is especially true in coarser resolution aerial photographs. Therefore for better identification percentages, agencies should fix to take the images after restriping the pavement markings.

Number of driveways were over estimated in 6-inch resolution based on the criteria set for driveways, such as presence of contrasting color features in a driveway, which leads to the belief that there are two driveways. In coarser resolutions, the distinction between closely spaced driveways may disappear, as shown in Figure 5.3. It should be noted that for all identification percentages below 95%, the resolution is not adequate for data collection. For example, the result of 52% of all through lanes being identified by 2-foot imagery is not acceptable. When collecting such data, the total number of lanes is required, not roughly half of them.

The identification percentage for some features such as shoulders could not be calculated in 1-meter images, as changes occurred from the date the 1-meter images were taken. Also the 24-inch images were in Mr. SID image format, which were coarser than 1-meter images in tiff format, this resulted in similar IP for both the data sets.



(a) 24-inch resolution aerial photograph, with no distinction between driveways



(b) 6-inch resolution aerial photograph, with distinction between driveways

Figure 5.3: Underestimation of driveways, as distinction between driveways disappears

CHAPTER 6. VARIATION IN FEATURE LOCATION

Introduction

In order to manually locate a feature on an image, the feature must be identified and located by an observer. Even if standard procedures are provided for the identification of a feature and selection of its location, there can be differences among observers in locating the same point, as manual location of a feature will require to identify the feature and then using the manual digitization method described in the chapter 3 locate the feature. This variation can be attributed to difference in how objects are perceived on images, observer experience in photo interpretation, and the care the observer takes in locating a feature. Further, as the resolution of aerial photographs decreases, objects on the images are less distinguishable, which can result in more observer variation. This variation among observers can result in inconsistent location data. Figure 6.1 illustrates the concept of variation in identifying a point by different observers. The center of the circle represents the mean location for several observers. The circle represents the standard deviation among observers. The location of the object according to each observer is represented as a star in different color.

Observer Variation Test

A test was performed to evaluate the variation in location of points among different observers. Set of features consisting of five to six elements were pre selected

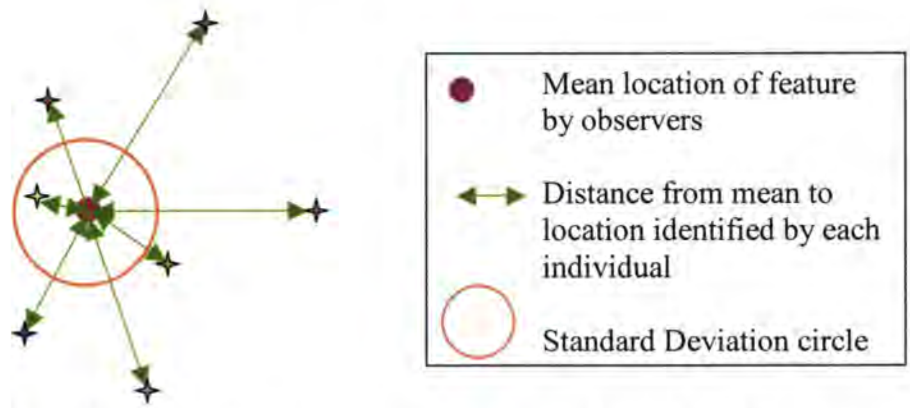


Figure 6.1: Location of a point by different observers and standard deviation among them

along the study area. For example six signs, 5 signal posts and 5 median openings were selected along the corridor. These elements were selected randomly to avoid any bias in selection. A total of 54 elements in 2-inch resolution, 42 elements in 6-inch resolution, 15 elements in 24-inch resolution and 15 elements in 1-meter resolution aerial photographs were selected. Seven observers familiar with ArcView were selected to identify and locate the same set of features. In each of the four pilot study data sets a polygon was drawn around each image to indicate the general location of each feature in the image as show in Figure 6.2. The general location was identified to direct the observers to a particular feature without biasing their final selection of location. Each observer was tested independently of the others to avoid bias. Directions were provided to observers as to how to locate a particular feature. This was done to avoid any discrepancy in locating features.

Figure 6.2: General location of features for observers

For all features, the observers were directed not to locate the center of the rectangle or circle drawn around each feature. For individual types of features, the following directions were provided:

1. Sign: Locate the central point where the signpost meets the ground.
2. Signal: Locate the central point where the signal post meets the ground. Some signal posts may have a concrete pedestal, then locate the southeast corner of the concrete pedestal.
3. Utility Poles: Locate the central point where the pole meets the ground.
4. Drainage Structures: Locate the southeast corner of the drainage box.

5. Pedestrian Crossing: Locate the southeast corner of intersection pedestrian crossings.
6. Medians: Locate the tip of the median. Medians are semi-circular in shape at their beginning or ending.
7. Intersections: Locate the center of intersecting approaches.
8. Driveways: Locate the center of the driveway at the edge of roadway.
9. RR Crossings: Locate the center of RR crossing and roadway intersection.
10. Bridges: Locate the southeast corner of the bridge.

Methodology

Manual digitization method was used by the observers to locate features in each image data set. ArcView Avenue scripts were developed to automatically update an attribute table with the location component of the features. Once the feature with in each polygon is identified, clicking on it as per the directions provided, will pop-up a window, which asks for the feature description and automatically updates the attribute table including coordinates of the features. Figure 6.3 depicts the pop-up window and updated attribute table.

Figure 6.4 shows the different location identified by each of the seven observers for a single point. The variation among the observers was calculated using standard deviation. Standard deviation is a measure of the dispersion or spread of data *(21)*. Standard deviation and mean were calculated for all feature types and are presented in the accuracy evaluation section later in this chapter. Standard deviation between observers is calculated in both X and Y directions for each feature. The minimum and maximum standard deviations within a set of same feature type such as signs, signals etc., is tabulated to produce a range of deviation in both X and Y directions. For example, out of four standard deviations calculated for four railroad crossings, the minimum and maximum standard deviations were obtained in both X and Y directions.

Accuracy Evaluation

The observers identified features on the aerial photographs and the location coordinates of each feature were updated in the attribute tables. The standard deviation among users was calculated for each element and the maximum and minimum standard deviations are presented in Tables 6.1, 6.2, 6.3 and 6.4, for the set of elements belonging to the same feature type. For example, in a 2-inch resolution aerial photograph, standard deviation among users is calculated at each of the six signs. The maximum and minimum standard deviation along X and Y directions is calculated from the set of these six standard deviations. The detailed standard deviation calculations are tabulated and presented in Appendix C.

Figures 6.5, 6.6, 6.7 and 6.8 depict the variation among observers for locating transportation features in inches. Each bar in the graph represents the magnitude of variation among different observers.

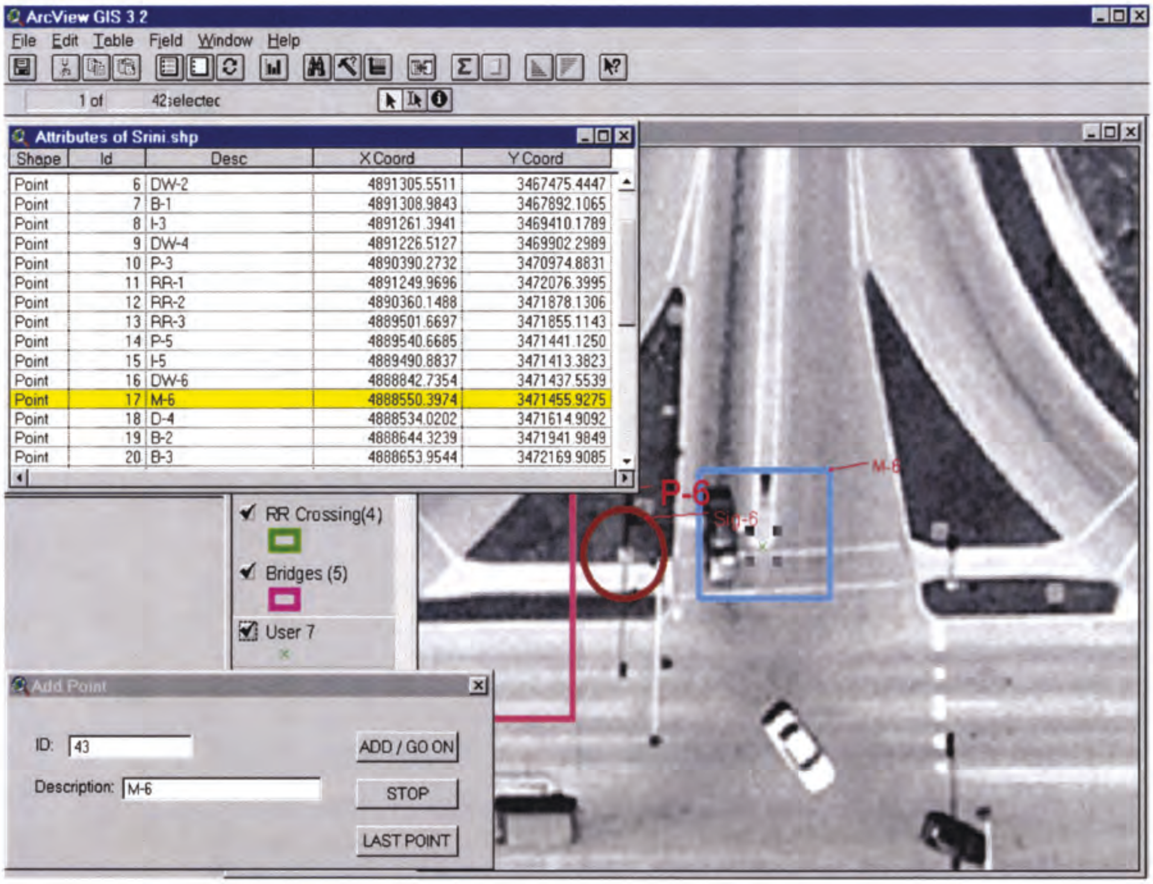


Figure 6.3: ArcView Avenue script for automatic updating of attributes

Results and Conclusions

As expected, it was observed from the results that higher resolution aerial photographs have less variation than coarse resolution aerials. As the resolution decreases from, it is seen that there is an increase in the amount of variation among observers, in both X and Y directions. This is especially true for bridges. For example, in 2-inch resolution the maximum standard deviation among observers along X direction was 75 inches, which increased to 206 inches in 1-meter resolution. But within data sets, it is evident from Tables 6.1 to 6.4 that there is no significant variation between observers.

Figure 6.4: Edge of drainage structure as located by seven observers

Table 6.1: 2-inch resolution standard deviation among observers

Feature	X (in inches)		Y (in inches)	
	Minimum	Maximum	Minimum	Maximum
Signs	0.87	11.72	1.23	11.60
Signals	2.12	18.57	2.03	26.30
Drainage Structures	0.00	5.05	0.00	1.73
Pedestrian Crossing	2.12	17.54	1.06	13.84
Medians	0.00	7.77	1.23	16.69
Intersections	20.51	50.24	11.62	53.79
Driveways	5.87	10.46	3.06	20.22
Utility Poles	0.00	20.31	2.21	14.75
Bridges	5.92	75.01	4.42	32.96
Railroad Crossings	5.61	14.57	5.58	14.75

Table 6.2: 6-inch resolution standard deviation among observers

Feature	X (in inches)		Y (in inches)	
	Minimum	Maximum	Minimum	Maximum
Signals	3.55	19.26	4.33	31.95
Drainage Structures	1.50	3.78	2.12	18.73
Pedestrian Crossing	2.68	4.02	1.06	4.11
Medians	1.90	29.21	1.94	47.49
Intersections	8.22	43.03	12.46	40.74
Driveways	6.30	10.78	5.81	18.24
Bridges	3.00	104.34	17.93	28.09
Railroad Crossings	1.64	5.20	4.02	10.14

Table 6.3: 24-inch resolution standard deviation among observers

Feature	X (in inches)		Y (in inches)	
	Minimum	Maximum	Minimum	Maximum
Intersections	13.19	44.74	14.18	53.45
Bridges	8.80	206.49	22.64	112.95
Railroad Crossings	9.05	14.10	9.72	72.04

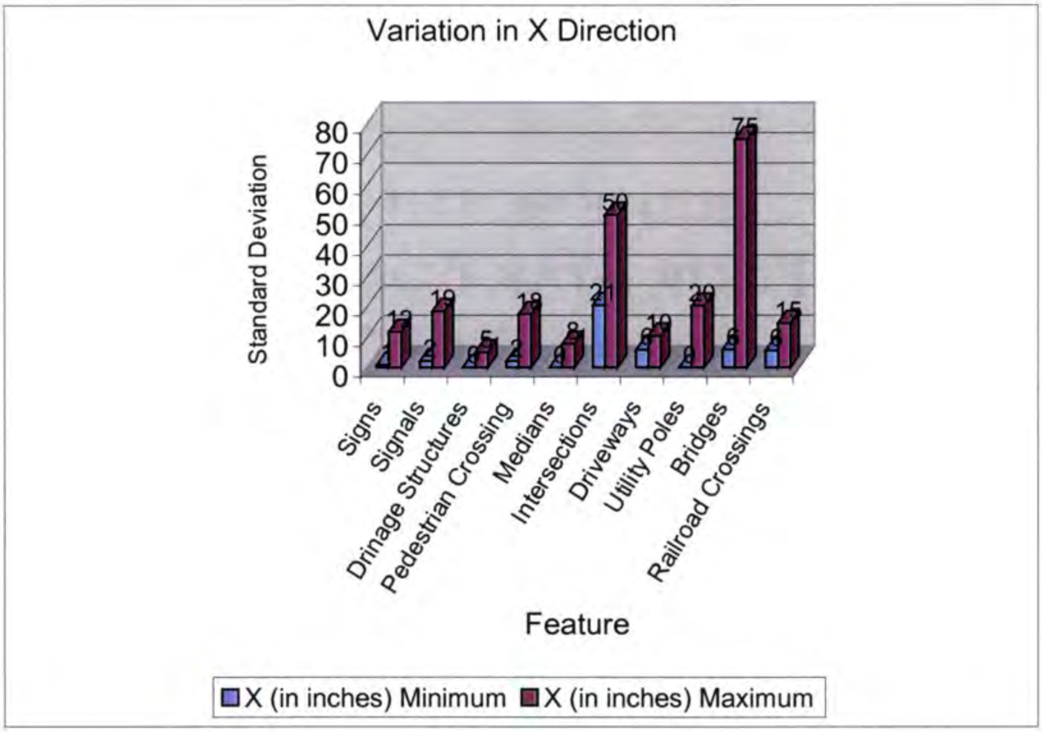
Table 6.4: 1-meter resolution standard deviation among observers

Feature	X (in inches)		Y (in inches)	
	Minimum	Maximum	Minimum	Maximum
Intersections	19.83	65.64	15.56	28.13
Bridges	22.42	206.35	27.10	117.80
Railroad Crossings	17.51	51.69	8.52	26.35

For features like intersections, where the observers were asked to locate the center of the feature, the variation decreased from 2-inches (53.79 inches) to 1-meter (28.13 inches). This can be attributed to the fact that all the observers were trying to locate the center more accurately in 2-inches than in 1-meter, as more detail view of the feature is possible in 2-inches.

More specific instructions as how to locate a feature may reduce the amount of variation among observers. It is seen that for features such as pedestrian crossings and drainage structures, there was no significant variation as specific directions to locate the southeast corner of the features were provided. For features such as intersections and driveways, there was more variation than pedestrian crossings and drainage structures, as the observers were asked to locate the center of the feature, which is not easy to locate compared to the location of a corner.

There was no specific pattern of variation among observers along X and Y directions. For some features like drainage structures, there is a large variation along Y direction than in X direction. This was because of the size and shape of the feature. Overall there is no significant variation with in a data set and, with specific location methodology and knowledge of ArcView, the variation among observers may be reduced.



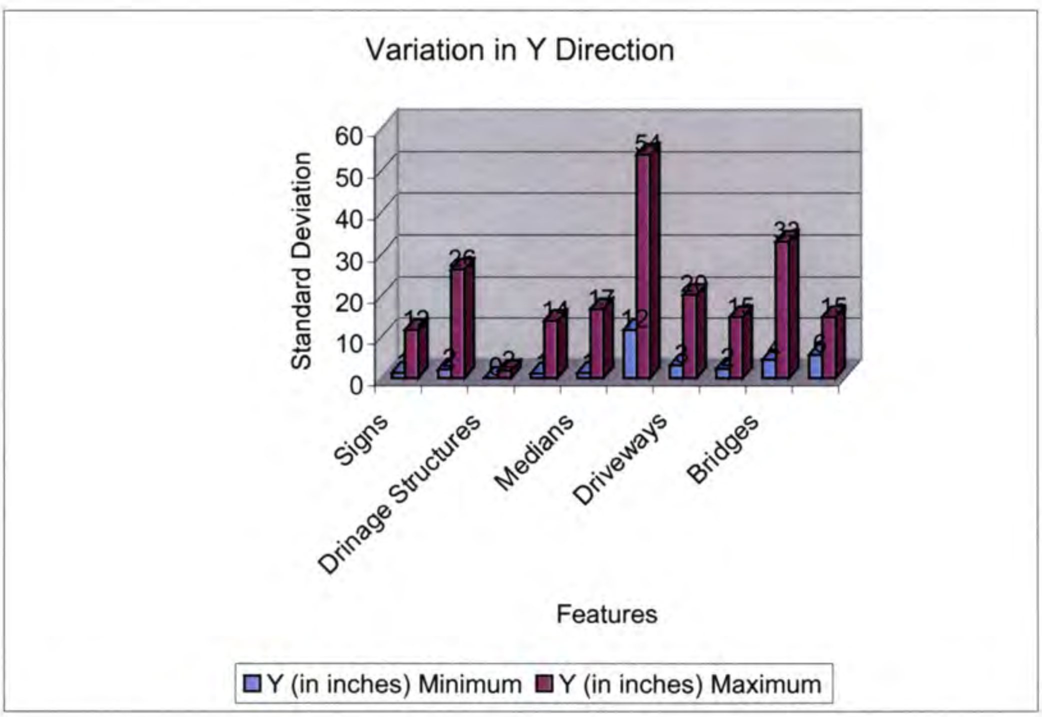
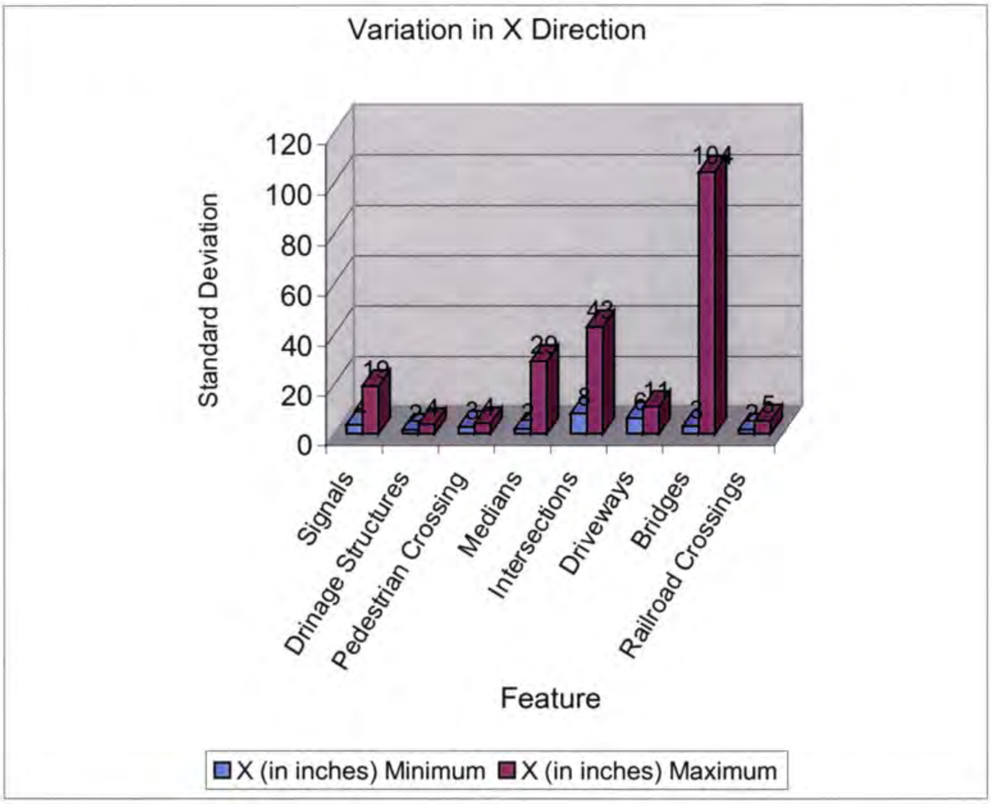


Figure 6.5: Observer variation in X and Y directions for 2-inch resolution image



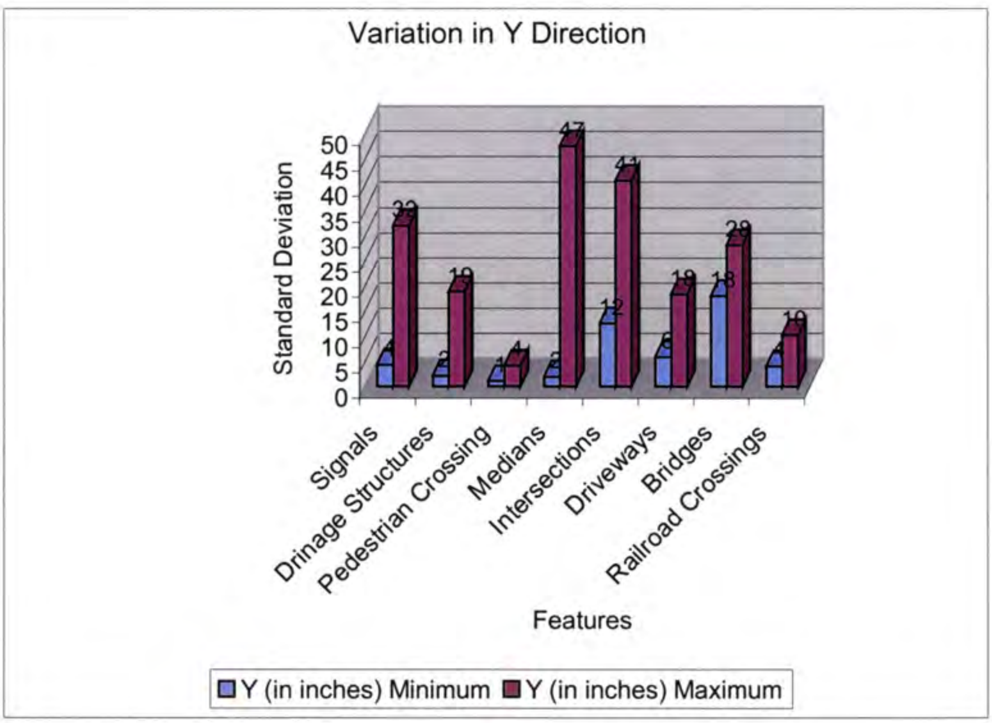


Figure 6.6: Observer variation in X and Y directions for 6-inch resolution image

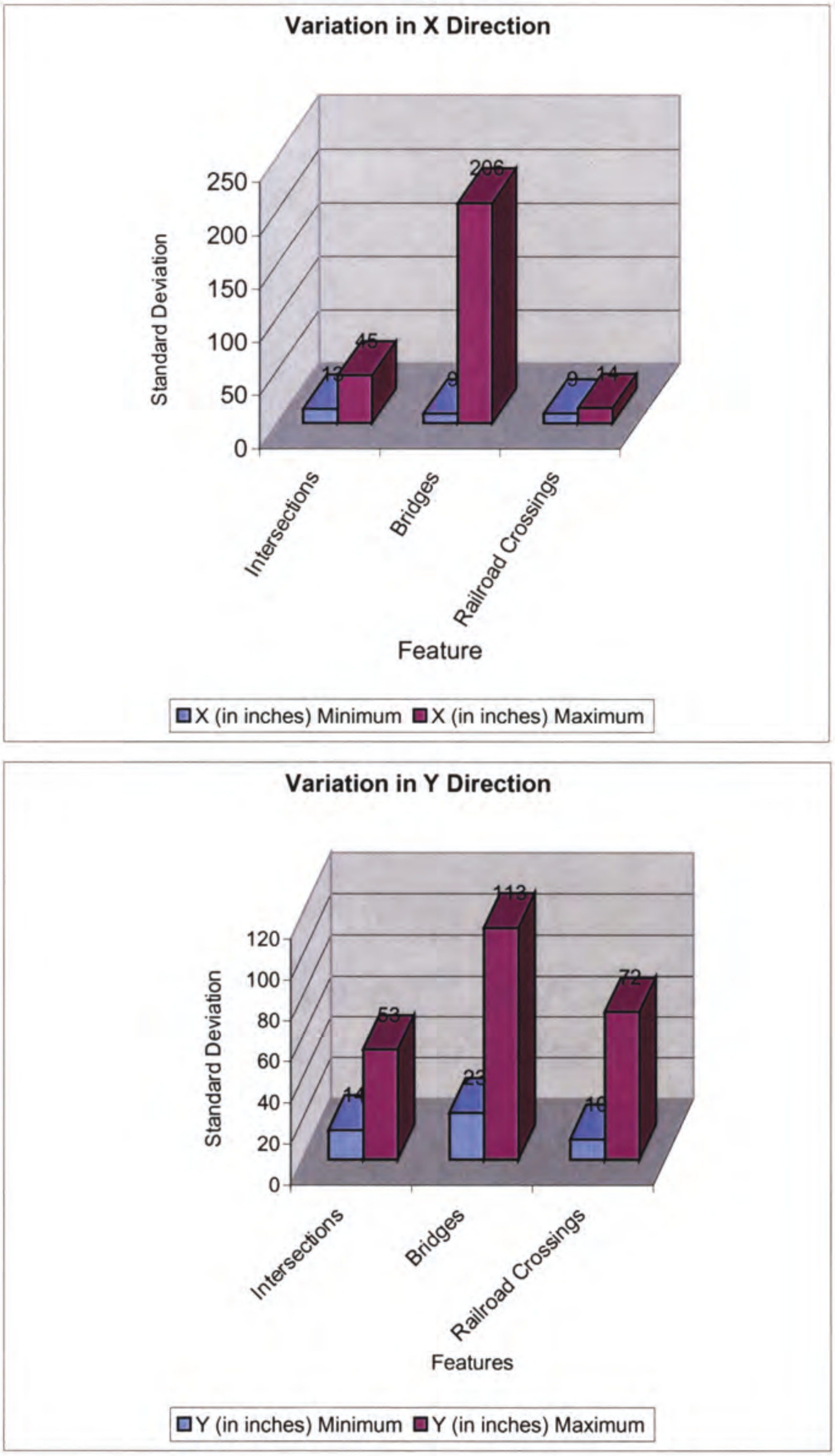
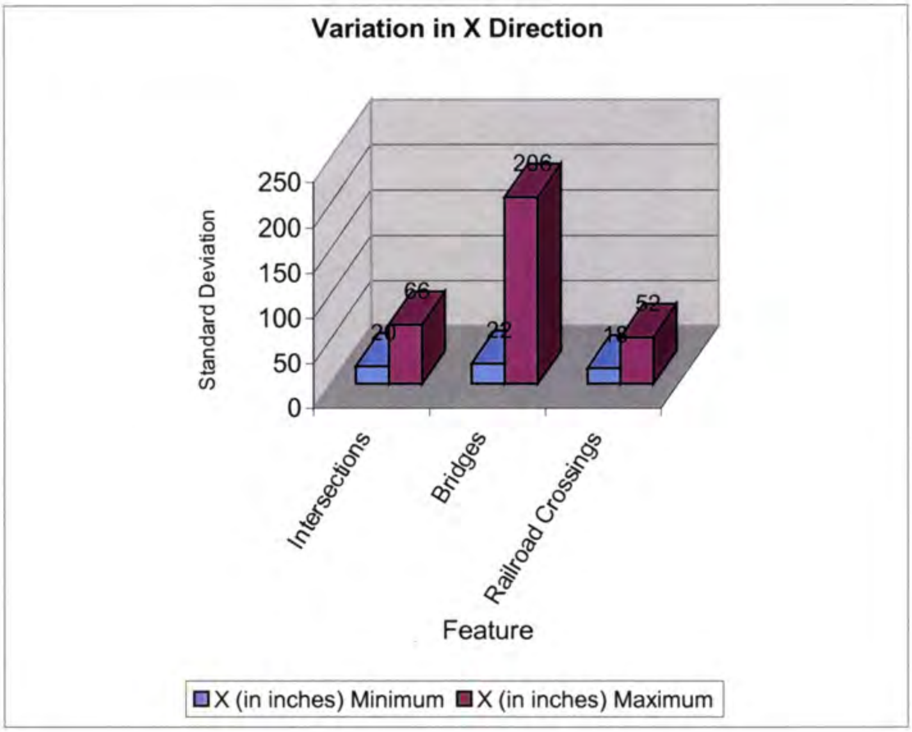


Figure 6.7: Observer variation in X and Y directions for 24-inch resolution image



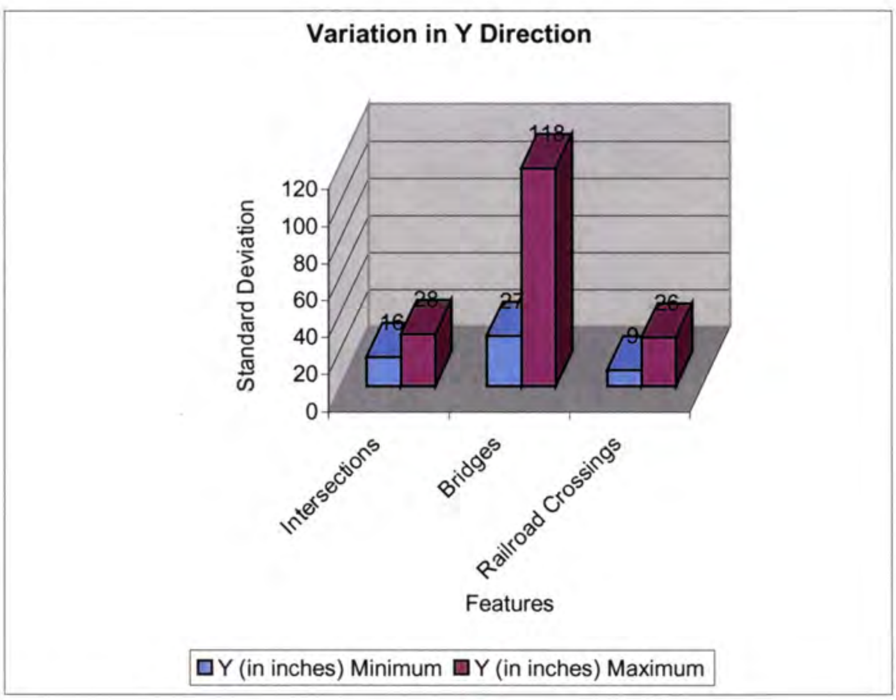


Figure 6.8: Observer variation in X and Y directions for 1-meter resolution image

CHAPTER 7: ACCURACY OF LINEAR MEASUREMENTS

Linear measurements are important attributes of inventory data apart from location and presence or absence of inventory elements. Linear measurements are used in many transportation applications such as highway design and traffic engineering. Accuracy required for linear measurement attributes depends on the application. For example, safety studies require higher accuracy data than capacity studies *(19)*. Current methods of data collection such as manual methods and videolog vans, measure linear features using Distance Measuring Instrument (DMI). In this chapter, the accuracy with which linear measurements can be obtained is evaluated. Measurements from all four aerial photograph data sets are compared to the true measurements on the ground, to evaluate the accuracy. The expected range of difference between the aerial photographs and the ground truth is computed using a t-test. The methodology followed and the results are described in the following sections.

Methodology

To evaluate the expected linear accuracy for each dataset, measurements of through lane widths, turn lane widths and lengths, median widths, and total roadway width for locations in the study area were made in the field and compared with those obtained from the imagery. Field measurements were made using a handheld DMI (accuracy ± 0.1 feet). The differences between the expected (field) and observed (images) lengths and widths for a specific feature were recorded and the t-test performed to estimate the 95% confidence intervals.

The t-statistic is given by:

$$t = \left[\frac{\bar{d} - \mu d}{sd / \sqrt{n}}\right]$$

Where:

$\bar{d} = \left[\frac{\Sigma d_i}{d_n}\right]$ the mean measurement difference

d_i is the difference between ground and aerial measurements, $(g_i - a_i)$

d_n is the total number of measurements made

$\mu d = 0$, the hypothesized difference

$Sd = \left[\frac{\Sigma (d_i - \bar{d})^2}{n - 1}\right]$ the standard deviation of the measurement differences

$\sqrt{n}$ is the square root of the sample size being examined

The test was performed at the 0.05 significance level.

A set of linear data elements tested from the four data sets was determined by reviewing features that are either required by the HPMS or those collected by the Iowa DOT. Using a handheld DMI, linear measurements were recorded in the field. Distances were measured on the images by identifying the beginning and ending points of each feature and using ArcView's distance tool. Map units were set in feet, allowing measurements to be made and recorded in feet. Figure 7.1 illustrates the procedure in ArcVirew.

Figure 7.1: Collection and Recording of Elements with 2-Foot Image

Each element required a standardized procedure for identification and measurement. The particular technique followed for the identification and measurement of each element was presented in Table 3.2 of chapter 3.

Results

The range of difference between the data sets and the field measurements is calculated using t-test and the results are shown in Tables 7.1 to 7.4. The sample size and the upper and lower bounds for the 95% confidence intervals are presented, as well as mean and standard deviation. In the 2-inch and 6-inch datasets, pavement markings and vegetation, which often delineate the various elements, were more readily visible, resulting in larger sample sizes. Larger sample sizes allowed more accurate error ranges to be computed. The reader is urged to interpret the error ranges generated for smaller sample sizes ($\leq$10) with caution, as the sample size is not statistically significant. Shoulder widths were also analyzed, but were later omitted due to limited sample size.

As demonstrated by Tables 7.1 and 7.2, lower resolution imagery does not perform nearly as well as the higher resolution datasets. Sample sizes were reduced, in part, because of the inability to distinguish features in the lower resolution images. In many cases, the 1-meter dataset ended up with less than 5 samples for many features.

Whether the linear measurements for a particular dataset are adequate again depends on the application. Only the 2-inch dataset consistently yielded the accuracy required for collection of data for roadway features to support highway safety design decisions described in National Cooperative Highway Research Program (NCHRP) report 430 *(19)*. For general information such as segment widths and lengths, lower resolution aerial photographs such as 1 meter are adequate. It should also be noted that length measurements were highly dependent on the ability to identify beginning and ending points of features.

In some cases, vegetation blocked the view of the roadway environment. While this vegetation did not adversely affect the collection and measurement of elements, it did create difficulties. For instance, Figure 7.2 displays a tree, which blocks the view of through lanes and signals at one test intersection.

Figure 7.2: Vegetation Obstruction of View

The primary conclusion drawn from this accuracy evaluation study is that both high and low-resolution imagery have a place in infrastructure data collection. Higher resolution images provide more accurate linear measurements, making them more applicable for collection of inventory data for LRS and highway safety. Lower resolution images are useful in inventorying data for traffic engineering purposes.

Table 7.1: Linear Measurement Error Ranges for 2-Inch Dataset

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	67	-0.07	0.24	0.09	0.65
Median Width	0.33	9	-1.14	2.83	0.84	2.59
Right Turn Lane Length	3.28	12	-2.76	-0.03	-1.40	2.14
Right Turn Lane Width	0.33	12	-0.86	0.53	-0.17	1.1
Left Turn Lane Length	3.28	17	-1.24	2.68	0.72	3.82
Left Turn Lane Width	0.33	19	-0.21	0.51	0.14	0.75
Total Roadway Width	Not Provided	20	-2.40	-0.28	-1.34	2.26

Table 7.2: Linear Measurement Error Ranges for 6-Inch Dataset

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	67	0.01	0.38	0.19	0.78
Median Width	0.33	9	-1.75	2.57	0.41	2.81
Right Turn Lane Length	3.28	10	-2.67	6.17	1.75	6.18
Right Turn Lane Width	0.33	12	-0.32	0.90	0.29	0.95
Left Turn Lane Length	3.28	17	-3.03	4.21	0.59	7.04
Left Turn Lane Width	0.33	17	0.39	0.54	0.07	0.96
Total Roadway Width	Not Provided	20	-1.51	3.49	1.00	5.34

Table 7.3: Linear Measurement Error Ranges for 24-Inch Dataset

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	17	-0.61	0.37	-0.12	0.95
Median Width	0.33	5	-3.55	8.48	2.46	4.84
Right Turn Lane Length	3.28	4	Sample size < 5	Sample size < 5	Sample size < 5	Sample size < 5
Right Turn Lane Width	0.33	6	-2.12	2.04	-0.04	1.98
Left Turn Lane Length	3.28	8	-3.97	3.00	-0.48	4.16
Left Turn Lane Width	0.33	7	-2.36	5.64	1.64	4.32
Total Roadway Width	Not provided	20	-3.56	2.96	-0.29	6.97

Table 7.4: Linear Measurement Error Ranges for 1-Meter Dataset

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	6	-1.13	0.80	-0.17	0.92
Median Width, right turn lane length and width, left turn length and width, sample size < 5						
Total Roadway Width	Not provided	12	-1.34	3.04	0.85	3.45

CHAPTER 8. SUMMARY AND CONCLUSIONS

In summary remotely sensed images are useful in inventorying transportation infrastructure features. The performance measures of the pilot study indicate that higher resolution images such as 2-inch and 6-inch are more accurate and almost all features can be extracted from them. 24-inch and 1-meter images have limitation on number of features that can be identified. But 24-inch and 1-meter images are still useful in inventorying the presence of features and for maintenance purposes. Lane width measurement errors varied from –0.12 to +0.24 feet (95% confidence interval) among the datasets. Even in the 2-inch dataset, errors ranged from a –2.4 to 2.83 feet. Given that common lane widths are 8 to 12 feet, a measurement error of almost 3 feet would be significant. As a result, except for 2-inch data set, none of the images demonstrated sufficient linear accuracy to measure roadway or lane widths, which would be used in applications such as capacity or safety studies. Length measurement errors varied from –3.97 to +6.17 feet (95% confidence interval) among the datasets. The minimum practical length for a left-turn lane (storage of approximately 5 cars) is about 100 feet. A 6-foot error is unlikely to affect capacity studies or calculation of maximum storage of left-turn lanes. As a result, all the datasets performed well for calculating length if the feature could be visually identified.

The primary conclusion of this study was that the most significant difference between the datasets was the ability to visually identify various inventory features. Most features were consistently identified in the 2-inch and 6-inch datasets. A significant drop in feature identification occurred in the 24-inch and 1-meter datasets. Length measurements and the ability to spatially locate a feature were significantly influenced by whether that feature could actually be identified in the first place. As a result, the limiting factor in using lower resolution datasets was whether a feature could be identified rather than whether it could be measured accurately. However, features were identified visually in this study, and the use of automated techniques such as sub-pixel analysis may improve feature identification in lower resolution imagery. Better image quality may also influence the ability to identify features.

The ability to identify a feature in order to locate it spatially was much more difficult with the lower resolution datasets. However, once features were identified, they could be spatially located fairly accurately. Even in the 1-meter dataset, point locations were located within 11 feet (95% confidence interval). It is expected that this accuracy would be sufficient for locating inventory elements such as utilities, signals, sidewalks, or drainage structures, for most applications. However, this accuracy may not be adequate for locating features for crash analysis. At 2-inch resolution, point locations were located within 2 feet (95% confidence interval), which is expected to be sufficient for capacity analysis and safety studies.

There was no significant location variation among individuals in identifying features on aerial photographs, except for bridges and intersections. It was seen that, if proper directions were provided for identifying and locating features, then the variation among observers was within 2 feet for most of the features, with the exception of bridges and intersections. For bridges and intersections, observers were not provided with precise location instructions, which resulted in large variation. It is expected that this variation is acceptable for inventory purposes and can be reduced with more precise instructions.

Results of this study suggest that lower resolution imagery's role is more limited than higher resolution imagery due to the inability to consistently identify various features. However, in circumstances where lower resolution data can be used, the main advantage is that it is cheaper than that of higher resolutions.

Advantages and Disadvantages of Remote Sensing for Inventory Data Collection

The main advantage of using remote sensing for collection of roadway inventory features is the reduced time for performing data collection compared to in-field methods such as GPS or video logging. Data collection at all resolutions resulted in a significant time savings when compared to manual data collection methods (GPS and linear measurements in the field). Figure 8.1 illustrates comparison of the time to collect length and width measurements in the field versus using images. Using remotely sensed images resulted in a 93% time savings compared to the GPS method for point data collection. A more detailed comparison of times is presented in Appendix D. The field collection times only include the time spent collecting data once on-site. Travel times to and from the sites, as well as between sites, were not recorded. These travel times could add substantially to the overall time required for manual data collection. Attributes of features were obtained more easily with imagery than with field methods, as the manual digitization method was employed for data extraction. Also, field methods use handheld

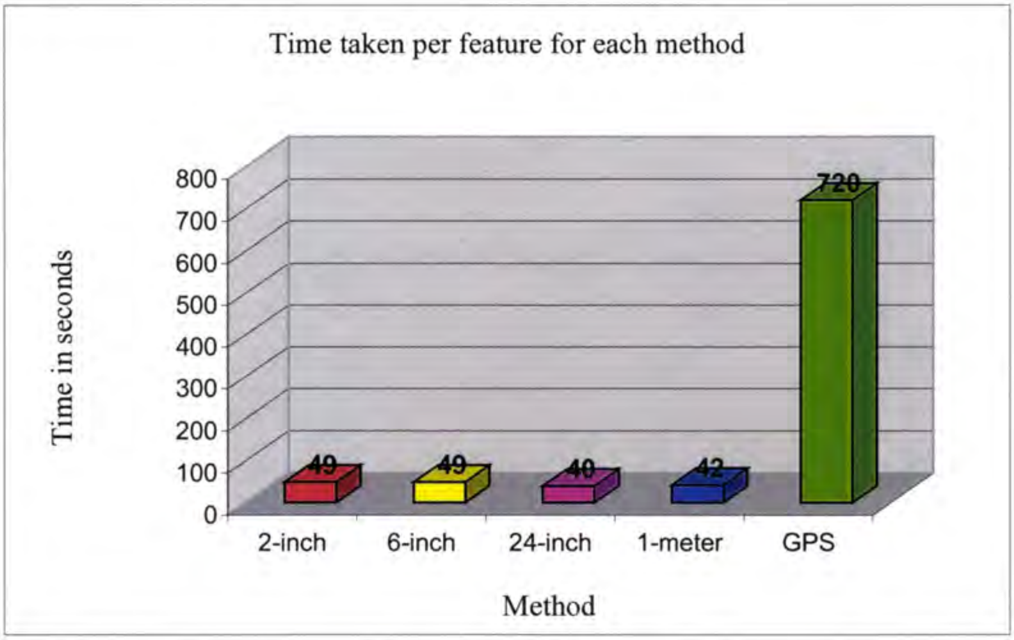


Figure 8.1: Seconds per Point to Spatially Locate a Point and Record Coordinates by Data Collection Method

GPS receivers in a majority *(2)* of instances for spatial data collection, which requires considerable time.

Spatial attributes of the features were obtained with relative accuracy and ease using aerial photographs. This resulted in an 87% time saving compared to data collection using handheld GPS units. A more detailed description of this comparison is presented in Appendix D.

Another advantage to the use of remotely sensed images in data collection is that workers do not need to be located on or near busy roadways, as may be the case for field data collection methods. Although workers are located inside a vehicle with video/photo logging, data collection must be conducted on-road, which may disrupt traffic. Field methods of data collection are limited to summer months because of weather conditions. Using remotely sensed images eliminates this particular restriction.

Aerial or satellite images also provide a permanent record. Once a site is flown, the images contain all features in the area studied whether they are used at the time or not. Additional data collection only entails going back to existing images rather than making additional trips to the field. Other advantages include:

- Georeferenced or ortho-rectified images are compatible with GIS
- Images can be shared among agencies (lower data costs)
- Multiple periods of data can be used for detection of change.
- No significant variation in location of features by different individuals

The main disadvantage of remote sensing is cost. A source at the Iowa Department of Transportation estimates that "raw" digital images can be practically obtained from a commercial vendor for approximately $100 per linear mile. Costs for ortho-rectification were not estimated since they are done in-house and no numbers were available for comparison. As shown in Table 8.1, costs for collection of points using a GPS exceed the costs of imagery, while the collection of features using a 3-camera panoramic videologging van with GPS are similar per mile to the costs of acquiring aerial imagery. Even so, collection of a significant amount of roadway would quickly become prohibitive for any of the methods shown. Videologging is much cheaper if a minimum amount of information, such as the number of signs per segment, rather than location of signs, is desired. A source at the Iowa DOT estimated that this type of video logging

Table 8.1: Comparison of Costs for Data Collection Methods

Data Collection Method	Data Collection Area	Total Cost (not including travel time)	Cost/Mile (not including travel time)
Kinematic GPS	55 points over four miles	$1,400	$350
3-Camera panoramic videologging van with GPS	One mile	$100 (if done as part of a much larger project)	$100
6-inch aerial images	One mile	$100 (if done as part of larger project)	$100 for acquisition of photos + time in house to ortho-rectify

costs approximately $11 per mile, not including the initial cost to purchase the van and equipment.

Problems encountered

Data Sets

The most notable problem encountered during the project was the lack of consistent imagery. Each of the four image sets were taken on different days and, in some cases, different years. For example, the 1-meter images were taken in 1994, while the 2-foot, 6-inch and 2-inch images were taken in 1998 or later. The result was that significant change had occurred, especially at 4 of the 10 study intersections. This resulted in the elimination of these intersections from the study when examining 1-meter images.

The quality of the imagery used was also problematic. Images were saved in different file formats (.tiff, .sid,) etc., which potentially degraded their quality. Image file conversion may have also created problems. For example, the 2-inch images were saved in a compressed .jpeg format after scanning. This format could not be read by the GIS software utilized by the researcher, requiring the images to be converted into .tiff format. This conversion may have degraded the quality of these images.

Finally, all imagery used in this research was panchromatic; no color imagery was acquired or used during any phase of the research. The belief on the part of the researcher is that color images would allow greater ease in element extraction. Color would allow features critical to linear measurement, such as pavement markings, to be viewed more prominently. This in turn would allow additional measurements to be made with greater ease and possibly accuracy.

Interpretation

Manual image interpretation presented the possibility for error. In the case of lower resolutions, some elements (signals, pavement markings) could not be identified at all. Without visible pavement markings, linear measurements could not be made in many cases. In the cases where such measurements could be made, their accuracy was questionable at best.

Linear measurements relied heavily on pavement markings. If the markings were worn out at the time images were taken, it created problems in measuring the features. Also, it was difficult to measure using the same beginning and ending points in the image as those used in the field. This may have resulted in additional error. In some cases individual lanes (through, right turn, left turn) were identified based on traffic movement, in the absence of pavement markings.

Recommendations

The conclusions drawn above provide an idea of what data images of various resolutions are capable of providing. Since each resolution provides different data, its application must be considered in light of what data an interested agency wishes to obtain. The resolution necessary will be determined by its ultimate application.

High-resolution imagery provides detailed inventory information. However, such images are costly to obtain, limiting the number of areas for which they are collected. Finding multiple user groups for the collected data sets would help spread the costs of collection out among users, as well as maximizing the use of the data. While high-resolution imagery is applicable for the type of widespread inventory collection required by the HPMS, the collection of such imagery for an entire state is currently neither financially feasible nor practical.

Instead, high-resolution imagery should be utilized for inventory collection at specific sites, such as intersections. Currently, inventories are not collected for such specialized locations on an individual basis. However, the need may arise for a safety study to be performed for a specific location, and the ability to quickly gather the necessary data would be useful. If recent, high-resolution imagery were available for that location, a time consuming trip into the field for data collection could be avoided. Instead, the desired data could be extracted from the aerial image. An added benefit to all of this is that if information concerning another element is later determined to be necessary, it can be quickly collected without making another expensive trip into the field.

Lower resolution imagery's role is limited by the data elements that can be extracted, but can be used for inventorying extractable elements for maintenance purposes. Data of lower resolutions, such as 1-meter and 24-inch, do cover wider land areas, which is an advantage over high-resolution imagery. Low-resolution imagery is also more affordable than that of higher resolutions. The key once again is to identify multiple user groups, which can utilize the data and spread the costs out.

If general information about the roadway environment is desired, then lower resolutions are recommended. Such general information includes roadway widths, segment lengths and intersection layout/alignment. Land uses are also identifiable from low-resolution imagery, as are the majority of the corresponding driveways for those land uses. In summary, low-resolution images provide a planar view for data collection, but they do not allow detailed information to be gathered.

The final recommendation is that the results presented here be viewed and interpreted with caution. The limited study of only one corridor and 10 intersections along it did not produce large samples of data, preventing extensive analysis from being performed. In many cases, the limited number of samples created some high identification percentages, when in fact, with a larger sample, these may have been significantly lower. As such, additional research is necessary to determine if this is the case.

Future Research

As a continuation of the current research, the possibility of automatic feature extraction should be explored. Automatic feature extraction may increase the ease of data collection while reducing collection times. Variation in the location of features by different individuals will be eliminated. Use of image analysis tools like training and classification, may help extract features that are difficult to extract by simply observing a photograph.

Color aerial photographs may enhance feature identification. All the datasets used for the research however, were panchromatic, which limited the ability to distinguish some key features. Another advantage of color images is that features such as signs can be categorized based on their color, which was a not possible using panchromatic images. This resulted in the reporting of sign presence but not sign type. Other images such as multi spectral and infrared images should also be explored for inventory data collection.

APPENDIX A. INVENTORY ELEMENTS

Table A.1: Identified inventory elements

Inventory Elements		Type of Sensing			
		Aerial			
		2 inch Geo Referenced	6 inch Orthorectified	2 Foot Orthorectified	1 m Simulated satellite image
3.1 Inventory	Sign Inventory	Yes	No	No	No
	Signal Inventory	Yes	Yes	No	No
	Number of Intersections	Yes	Yes	Yes	Yes
	Number of Lanes	Yes	Yes	No	No
	Number of Turning Lanes	Yes	Yes	Yes	Yes
	Number of Railroad	Yes	Yes	Yes	Yes
	Number of Railroad Tracks	Yes	Yes	Yes	Yes
	Number of Driveways	Yes	Yes	Yes	Yes
	Driveway Land Use	Yes	Yes	Yes	Yes
	Bicycle Lanes/ Side Walks	Yes	Yes	Yes	Yes
	Presence of Median	Yes	Yes	Yes	Yes
	Number of 2-way Left Turn	Yes	Yes	No	No
	1 or 2 Way Median Opening	Yes	Yes	Yes	Yes
	Interchange Design	Yes	Yes	Yes	No
	Number of separations	Yes	Yes	Yes	Yes
	Number of Bridges	Yes	Yes	Yes	Yes
	Pedestrian Crossing	Yes	Yes	No	No
	On-street Parking	Yes	Yes	Yes	No
	Drainage Structures	Yes	Yes	No	No
	Number of Utility Poles	Yes	Yes	No	No
3.2 Location	Sign Location	Yes	No	No	No
	Signal Location	Yes	Yes	No	No
	Utility Pole Location	Yes	Yes	No	No
	Drainage Structure Location	Yes	Yes	No	No
	Pedestrian Crossing Location	Yes	Yes	No	No
	Median Location	Yes	Yes	Yes	Yes
	Intersection Location	Yes	Yes	Yes	Yes
	Driveway Location	Yes	Yes	Yes	Yes
	RR crossing Location	Yes	Yes	Yes	Yes
	Bridge Location	Yes	Yes	Yes	Yes
3.3 Measurement	Right of Way Width	Yes	Yes	Yes	Yes
	Width of Lanes (Thru/turn)	Yes	Yes	No	No
	Length of Lanes (Thru/Turn)	Yes	Yes	Yes	Yes
	Width of Shoulders	Yes	Yes	No	No
	Bridge Width	Yes	Yes	Yes	Yes
	Bridge Length	Yes	Yes	Yes	Yes
	Median Opening Width	Yes	Yes	No	No
	Length of Median	Yes	Yes	No	No
	Driveway Width	Yes	Yes	Yes	Yes

APPENDIX B. POSITIONAL ACCURACY

Table B.1: GPS coordinates in State Plane Iowa North system and NAD 1983 datum

GPS Coordinates for Planimetric Points			
ID	North	East	Elevation
1	3463500.760	4890581.180	902.670
2	3463496.960	4891232.530	903.240
3	3465417.980	4890381.980	903.440
4	3464219.960	4891644.850	895.470
5	3466165.190	4890919.140	903.850
6	3466132.550	4892018.840	887.900
7	3466790.710	4890955.890	898.560
8	3467603.500	4890951.020	893.680
9	3468784.650	4891223.620	887.620
10	3468940.300	4891320.050	886.690
11	3469431.740	4890755.990	888.140
12	3469866.100	4891209.690	888.370
13	3470978.680	4890755.570	901.350
14	3471377.860	4890755.490	906.910
15	3472008.400	4890392.280	917.500
16	3472095.160	4891210.590	919.530
17	3471477.110	4888629.180	910.160
18	3471472.060	4888468.360	910.600
19	3472511.550	4889173.260	920.710
20	3472438.350	4888634.410	919.870
21	3473614.390	4889064.870	922.820
22	3473592.320	4888238.080	927.940
23	3474108.680	4888539.530	926.320
24	3474738.240	4888589.330	930.840
25	3475654.620	4889461.810	936.790
26	3475689.900	4888267.510	941.810
27	3477059.490	4889021.470	945.720
28	3477008.060	4888265.630	953.730
29	3481760.110	4889025.730	958.160
30	3481754.210	4888317.410	954.120
31	3481036.940	4888603.690	962.750
32	3481673.140	4887439.790	951.910
33	3470796.820	4884890.320	895.720
34	3471371.320	4886731.970	903.510
35	3471432.490	4886824.480	903.530
36	3471365.000	4886492.020	904.160
37	3468607.630	4891225.180	887.800
38	3469430.490	4891370.670	885.880
39	3470449.740	4890988.610	901.310
40	3470915.720	4890347.630	911.250
41	3472157.500	4889145.720	915.030
42	3473225.620	4888541.310	925.470
43	3475226.860	4888516.690	936.190
44	3477403.660	4887878.560	956.110
45	3477394.150	4887109.140	959.700
46	3477760.320	4889460.500	958.500
47	3474084.260	4889425.260	925.840
48	3472807.050	4887992.070	927.350
49	3471439.240	4887983.060	913.930
50	3472807.450	4889439.370	921.390
51	3470445.430	4890339.160	910.540
52	3463496.700	4890272.010	904.180
53	3466146.060	4890599.470	904.690
54	3480010.180	4888546.850	961.670
55	3470286.340	4885153.290	896.170

Table B.2: Positional Accuracy for 2-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+
		GPS	2 Inch aerial			GPS	2 Inch aerial			(Diff in Y)^2
1	(D) Airport Road, Near to Sams club Parking Lot	4890581.180	4890579.402	1.778	3.160	3463500.760	3463500.708	0.052	0.003	3.163
6	(D) S. 16th Street West, Away from the X	4892018.840	4892017.990	0.850	0.722	3466132.550	3466131.691	0.859	0.738	1.461
7	(D) Near to K-Mart Parking Lot on Buckeye	4890955.890	4890955.810	0.080	0.006	3466790.710	3466790.659	0.051	0.003	0.009
8	(D) On Buckeye, to the end, near Red Lobster	4890951.020	4890949.857	1.163	1.353	3467603.500	3467603.472	0.028	0.001	1.354
17	(D) Lincoln Way & Grand Ave, Near H-Video	4888629.180	4888629.038	0.142	0.020	3471477.110	3471477.050	0.060	0.004	0.024
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888468.169	0.191	0.036	3471472.060	3471471.572	0.488	0.239	0.275
21	(S) Wilson Ave & 8th St	4889064.870	4889064.693	0.177	0.031	3473614.390	3473614.933	-0.543	0.295	0.326
22	(S) Hodge Ave & 8th St	4888238.080	4888238.258	-0.178	0.032	3473592.320	3473591.994	0.326	0.106	0.138
23	(S) Grand Ave & 9th St	4888539.530	4888539.675	-0.145	0.021	3474108.680	3474108.690	-0.010	0.000	0.021
24	(S) Grand Ave & 11th St	4888589.330	4888590.055	-0.725	0.526	3474738.240	3474739.537	-1.296	1.681	2.207
26	(S) Harding Ave & 13th St	4888267.510	4888266.998	0.512	0.263	3475689.900	3475688.399	1.501	2.252	2.515
27	(S) Wilson Ave & 16th St	4889021.470	4889020.263	1.207	1.458	3477059.490	3477058.216	1.274	1.622	3.080
28	(S) Harding Ave & 16th St	4888265.630	4888266.211	-0.581	0.338	3477008.060	3477008.783	-0.723	0.522	0.860
29	(S) Duff Ave & Jenson Ave	4889025.730	4889024.950	0.780	0.608	3481760.110	3481759.982	0.128	0.016	0.624
30	(S) Bus Stop near Wal-Mart parking lot	4888317.410	4888318.065	-0.655	0.429	3481754.210	3481754.101	0.109	0.012	0.441
31	(A) Access road on 28th St, next to Grand Ave	4888603.690	4888604.460	-0.770	0.592	3481036.940	3481037.361	-0.421	0.177	0.769
32	(S) 30th St & Ferndale Ave	4887439.790	4887439.566	0.224	0.050	3481673.140	3481673.097	0.043	0.002	0.052
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884890.212	0.108	0.012	3470796.820	3470796.590	0.230	0.053	0.065
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886731.781	0.189	0.036	3471371.320	3471371.320	0.000	0.000	0.036
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886824.187	0.293	0.086	3471432.490	3471432.479	0.012	0.000	0.086
36	(A) Access road from house to Lincoln Way	4886492.020	4886492.664	-0.644	0.415	3471365.000	3471365.123	-0.123	0.015	0.430

Table B.2: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)^2
		GPS	2 Inch aerial			GPS	2 Inch aerial			
38	(D) S. 5th St, next to Pizza Hut	4891370.670	4891370.725	-0.055	0.003	3469430.490	3469432.067	-1.577	2.486	2.489
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890347.275	0.355	0.126	3470915.720	3470914.907	0.813	0.661	0.787
42	(D) Grand Ave & 7th St	4888541.310	4888541.346	-0.036	0.001	3473225.620	3473225.805	-0.184	0.034	0.035
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887878.069	0.491	0.241	3477403.660	3477404.718	-1.058	1.119	1.360
55	(D) On Access road to Hilton Coliseum	4885153.290	4885153.318	-0.028	0.001	3470286.340	3470286.373	-0.033	0.001	0.002
								Sum		22.608 ft
								Average		0.870 ft
								RMSE		0.932 ft
								NSSDA		1.614 ft

D = Drainage Structure

A = Access Road

S = Side Walk intersection

Notes:
A circle of 0.93 ft radius defines horizontal RMSE
Positional Accuracy: Tested 1.61 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 1.61 ft of its true location, as best as its true location has been determined 95% of the time.)

Table B.3: Positional Accuracy for 6-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	6 Inch aerial			GPS	6 Inch aerial			
1	(D) Airport Road, Near to Sams club Parking Lot	4890581.180	4890579.487	1.693	2.866	3463500.760	3463501.003	-0.243	0.059	2.925
2	(S) Airport Road & S. Duff X. NW Side Walk	4891232.530	4891230.999	1.531	2.343	3463496.960	3463497.476	-0.516	0.267	2.609
3	(A) S. 17th Street	4890381.980	4890380.039	1.941	3.769	3465417.980	3465417.984	-0.004	0.000	3.769
4	(S) S. Duff. Near to US 30 E Ramp	4891644.850	4891642.515	2.335	5.452	3464219.960	3464220.974	-1.014	1.028	6.481
5	(S) S. 16th Street & Buckeye Road	4890919.140	4890917.011	2.129	4.533	3466165.190	3466165.493	-0.303	0.092	4.625
6	(D) S. 16th Street West, Away from the intersection	4892018.840	4892016.971	1.869	3.493	3466132.550	3466132.952	-0.402	0.162	3.655
7	(D) Near to K-Mart Parking Lot on Buckeye	4890955.890	4890953.516	2.374	5.637	3466790.710	3466790.997	-0.287	0.082	5.720
8	(D) On Buckeye, to the end, near Red Lobster	4890951.020	4890949.006	2.014	4.055	3467603.500	3467603.527	-0.027	0.001	4.056
9	(S) S. Duff Ave, Near to Happy Joes	4891223.620	4891221.457	2.163	4.679	3468784.650	3468784.551	0.100	0.010	4.689
10	(S) S. Duff Ave, near to Honda	4891320.050	4891317.038	3.013	9.075	3468940.300	3468939.990	0.310	0.096	9.171
11	(S) Bus Stop near to River Breach Apt	4890755.990	4890753.955	2.035	4.140	3469431.740	3469432.503	-0.763	0.582	4.721
12	(S) Side Walk on S. Duff Ave near to Arby's	4891209.690	4891207.958	1.732	3.001	3469866.100	3469866.474	-0.374	0.140	3.141
13	(S) Sherman Ave & S. 2nd St	4890755.570	4890753.482	2.088	4.359	3470978.680	3470978.999	-0.319	0.102	4.461
14	(S) Sherman Ave & Lincoln Way	4890755.490	4890753.019	2.471	6.107	3471377.860	3471378.483	-0.623	0.388	6.495
15	(S) Kellogg Ave, Next to Parking Lot	4890392.280	4890389.534	2.746	7.541	3472008.400	3472009.023	-0.623	0.389	7.930
16	(S) Duff Ave, Near to RR Tracks	4891210.590	4891208.937	1.653	2.732	3472095.160	3472095.959	-0.799	0.639	3.371
17	(D) Lincoln Way & Grand Ave, Near H-Video	4888629.180	4888627.306	1.874	3.511	3471477.110	3471478.231	-1.121	1.256	4.767
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888466.496	1.864	3.475	3471472.060	3471473.148	-1.088	1.184	4.659
19	(S) Bus Stop on 5th St, near to City Hall	4889173.260	4889171.022	2.238	5.010	3472511.550	3472512.513	-0.963	0.927	5.937
20	(S) Grand Ave & 5th St	4888634.410	4888632.037	2.373	5.631	3472438.350	3472438.957	-0.607	0.368	5.999
21	(S) Wilson Ave & 8th St	4889064.870	4889062.526	2.344	5.497	3473614.390	3473615.038	-0.648	0.420	5.916
22	(S) Hodge Ave & 8th St	4888238.080	4888236.992	1.088	1.184	3473592.320	3473593.978	-1.658	2.750	3.933
23	(S) Grand Ave & 9th St	4888539.530	4888537.003	2.527	6.386	3474108.680	3474109.542	-0.861	0.742	7.128
24	(S) Grand Ave & 11th St	4888589.330	4888587.033	2.297	5.278	3474738.240	3474739.494	-1.254	1.573	6.851

Table B.3: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	6 Inch aerial			GPS	6 Inch aerial			
25	(S) Clark Ave & 13th St	4889461.810	4889459.989	1.821	3.316	3475654.620	3475654.549	0.072	0.005	3.322
26	(S) Harding Ave & 13th St	4888267.510	4888264.476	3.034	9.206	3475689.900	3475690.112	-0.212	0.045	9.251
27	(S) Wilson Ave & 16th St	4889021.470	4889019.982	1.488	2.215	3477059.490	3477059.525	-0.035	0.001	2.216
28	(S) Harding Ave & 16th St	4888265.630	4888263.524	2.106	4.436	3477008.060	3477008.545	-0.485	0.235	4.671
29	(S) Duff Ave & Jenson Ave	4889025.730	4889023.473	2.257	5.093	3481760.110	3481761.007	-0.897	0.804	5.898
30	(S) Bus Stop near Wall-mart parking lot	4888317.410	4888315.459	1.952	3.808	3481754.210	3481756.021	-1.811	3.278	7.087
31	(A) Access road on 28th St, next to Grand Ave	4888603.690	4888601.514	2.176	4.736	3481036.940	3481037.984	-1.044	1.090	5.826
32	(S) 30th St & Ferndale Ave	4887439.790	4887437.482	2.308	5.327	3481673.140	3481674.482	-1.342	1.800	7.127
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884887.954	2.366	5.600	3470796.820	3470796.056	0.764	0.583	6.183
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886729.480	2.490	6.202	3471371.320	3471371.503	-0.183	0.033	6.235
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886821.999	2.481	6.156	3471432.490	3471432.989	-0.498	0.249	6.405
36	(A) Access road from house to Lincoln Way	4886492.020	4886490.511	1.509	2.276	3471365.000	3471366.010	-1.010	1.020	3.296
37	(S) End Side Walk near to Happy Joes	4891225.180	4891223.970	1.210	1.465	3468607.630	3468607.529	0.101	0.010	1.475
38	(D) S. 5th St, next to Pizza Hut	4891370.670	4891368.504	2.166	4.690	3469430.490	3469430.560	-0.070	0.005	4.695
39	(S) S. 3rd St, next to parking lot	4890988.610	4890986.510	2.100	4.409	3470449.740	3470449.429	0.311	0.097	4.506
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890345.025	2.605	6.784	3470915.720	3470916.461	-0.741	0.549	7.333
41	(S) Next to parking lot on Main St	4889145.720	4889143.024	2.696	7.268	3472157.500	3472158.036	-0.536	0.287	7.555
42	(D) Grand Ave & 7th St	4888541.310	4888539.979	1.331	1.773	3473225.620	3473225.991	-0.371	0.138	1.911
43	(S) Grand Ave & 12th St	4888516.690	4888514.997	1.693	2.865	3475226.860	3475227.522	-0.662	0.438	3.303
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887876.939	1.621	2.629	3477403.660	3477404.573	-0.913	0.833	3.462
45	(S) Murray Dr & Northwestern Ave	4887109.140	4887106.529	2.611	6.816	3477394.150	3477394.977	-0.827	0.683	7.499
46	(S) Clark Ave & 18th St	4889460.500	4889458.009	2.491	6.207	3477760.320	3477760.988	-0.668	0.446	6.654
47	(D) Clark Ave & 9th ST	4889425.260	4889423.031	2.229	4.969	3474084.260	3474084.954	-0.694	0.482	5.451
48	(D) 6th St & Northwestern Ave	4887992.070	4887990.468	1.602	2.567	3472807.050	3472807.530	-0.480	0.230	2.797

Table B.3: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	6 Inch aerial			GPS	6 Inch aerial			
49	(S) Bus Stop near to ISU Credit Union, Opp DOT	4887983.060	4887980.588	2.472	6.113	3471439.240	3471440.456	-1.216	1.479	7.592
50	(S) Clark Ave & 6th St, Near to City Hall	4889439.370	4889437.482	1.888	3.564	3472807.450	3472808.471	-1.021	1.043	4.607
51	(D) S. 3rd St & Kellogg Ave	4890339.160	4890337.519	1.641	2.694	3470445.430	3470446.010	-0.579	0.336	3.030
52	(D) On Airport Rd, next to SAM's Parking lot	4890272.010	4890270.534	1.476	2.180	3463496.700	3463496.981	-0.281	0.079	2.259
53	(D) On S. 16th St next to K-Mart parking lot	4890599.470	4890597.476	1.994	3.977	3466146.060	3466146.527	-0.467	0.218	4.196
54	(D) On Grand Ave, next to First National Bank	4888546.850	4888544.519	2.331	5.436	3480010.180	3480010.964	-0.784	0.615	6.051
55	(D) On Access road to Hilton Coliseum	4885153.290	4885151.913	1.377	1.897	3470286.340	3470287.497	-1.157	1.339	3.236

Sum	278.136	ft
Average	5.057	ft
RMSE	2.249	ft
NSSDA	3.892	ft

D = Drainage Structure

A = Access Road

S = Side Walk intersection

Notes:
A circle of 2.25 ft radius defines horizontal RMSE
Positional Accuracy: Tested 3.89 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 3.89 ft of its true location, as best as its true location has been determined 95% of the time.)

Table B.4: Positional Accuracy for 24-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	24 Inch aerial			GPS	24 Inch aerial			
3	(A) S. 17th Street	4890381.980	4890384.108	-2.128	4.528	3465417.980	3465415.905	2.075	4.306	8.834
4	(S) S. Duff. Near to US 30 E Ramp	4891644.850	4891644.155	0.695	0.483	3464219.960	3464217.926	2.034	4.137	4.620
5	(S) S. 16th Street & Buckeye Road	4890919.140	4890918.210	0.930	0.865	3466165.190	3466164.084	1.106	1.223	2.088
9	(S) S. Duff Ave, Near to Happy Joes	4891223.620	4891224.181	-0.561	0.315	3468784.650	3468786.101	-1.451	2.105	2.420
10	(S) S. Duff Ave, near to Honda	4891320.050	4891319.921	0.129	0.017	3468940.300	3468938.173	2.127	4.524	4.541
11	(S) Bus Stop near to River Breach Apt	4890755.990	4890755.998	-0.008	0.000	3469431.740	3469429.953	1.787	3.193	3.193
12	(S) Side Walk on S. Duff Ave near to Arby's	4891209.690	4891208.102	1.588	2.522	3469866.100	3469866.049	0.051	0.003	2.524
13	(S) Sherman Ave & S. 2nd St	4890755.570	4890753.992	1.578	2.490	3470978.680	3470978.058	0.622	0.387	2.877
14	(S) Sherman Ave & Lincoln Way	4890755.490	4890758.045	-2.555	6.528	3471377.860	3471374.143	3.717	13.816	20.344
15	(S) Kellogg Ave, Next to Parking Lot	4890392.280	4890394.033	-1.753	3.073	3472008.400	3472010.013	-1.613	2.602	5.675
16	(S) Duff Ave, Near to RR Tracks	4891210.590	4891210.076	0.514	0.264	3472095.160	3472091.908	3.252	10.576	10.840
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888467.161	1.199	1.438	3471472.060	3471471.963	0.097	0.009	1.447
19	(S) Bus Stop on 5th St, near to City Hall	4889173.260	4889175.944	-2.684	7.204	3472511.550	3472508.019	3.531	12.468	19.672
20	(S) Grand Ave & 5th St	4888634.410	4888636.175	-1.765	3.115	3472438.350	3472435.951	2.399	5.755	8.870
21	(S) Wilson Ave & 8th St	4889064.870	4889064.003	0.867	0.752	3473614.390	3473613.978	0.412	0.170	0.921
22	(S) Hodge Ave & 8th St	4888238.080	4888233.959	4.121	16.983	3473592.320	3473588.021	4.299	18.481	35.464
24	(S) Grand Ave & 11th St	4888589.330	4888588.046	1.284	1.649	3474738.240	3474738.057	0.183	0.033	1.682
25	(S) Clark Ave & 13th St	4889461.810	4889457.994	3.816	14.562	3475654.620	3475654.051	0.569	0.324	14.886
26	(S) Harding Ave & 13th St	4888267.510	4888269.960	-2.450	6.003	3475689.900	3475692.021	-2.121	4.499	10.501
27	(S) Wilson Ave & 16th St	4889021.470	4889018.159	3.311	10.963	3477059.490	3477059.994	-0.504	0.254	11.217
28	(S) Harding Ave & 16th St	4888265.630	4888268.037	-2.407	5.794	3477008.060	3477010.013	-1.953	3.814	9.608
29	(S) Duff Ave & Jenson Ave	4889025.730	4889022.120	3.610	13.032	3481760.110	3481762.114	-2.004	4.016	17.048
32	(S) 30th St & Ferndale Ave	4887439.790	4887442.079	-2.289	5.240	3481673.140	3481671.995	1.145	1.311	6.551
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884888.035	2.285	5.221	3470796.820	3470796.010	0.810	0.656	5.877

Table B.4: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	24 Inch aerial			GPS	24 Inch aerial			
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886732.083	-0.113	0.013	3471371.320	3471370.098	1.222	1.493	1.506
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886823.991	0.489	0.239	3471432.490	3471436.060	-3.570	12.745	12.984
36	(A) Access road from house to Lincoln Way	4886492.020	4886490.036	1.984	3.936	3471365.000	3471363.975	1.025	1.051	4.987
37	(S) End Side Walk near to Happy Joes	4891225.180	4891225.947	-0.767	0.588	3468607.630	3468605.987	1.643	2.699	3.288
39	(S) S. 3rd St, next to parking lot	4890988.610	4890988.086	0.524	0.275	3470449.740	3470450.010	-0.270	0.073	0.347
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890348.169	-0.539	0.291	3470915.720	3470911.941	3.779	14.281	14.571
41	(S) Next to parking lot on Main St	4889145.720	4889152.191	-6.471	41.874	3472157.500	3472156.110	1.390	1.932	43.806
43	(S) Grand Ave & 12th St	4888516.690	4888517.981	-1.291	1.667	3475226.860	3475230.044	-3.184	10.138	11.805
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887878.032	0.528	0.279	3477403.660	3477406.096	-2.436	5.934	6.213
45	(S) Murray Dr & Northwestern Ave	4887109.140	4887112.129	-2.989	8.934	3477394.150	3477396.048	-1.898	3.602	12.537
46	(S) Clark Ave & 18th St	4889460.500	4889460.027	0.473	0.224	3477760.320	3477761.989	-1.669	2.786	3.009
49	(S) Bus Stop near to ISU Credit Union, Opp DOT	4887983.060	4887984.051	-0.991	0.982	3471439.240	3471439.966	-0.726	0.527	1.509
50	(S) Clark Ave & 6th St, Near to City Hall	4889439.370	4889440.184	-0.814	0.663	3472807.450	3472803.929	3.521	12.397	13.060

Sum	341.323	ft
Average	9.225	ft
RMSE	3.037	ft
NSSDA	5.257	ft

D = Drainage Structure
A = Access Road
S = Side Walk intersection

Notes:
A circle of 3.04 ft radius defines horizontal RMSE
Positional Accuracy: Tested 5.26 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 3.89 ft of its true location, as best as its true location has been determined 95% of the time.)

Table B.5: Positional Accuracy for 1-meter resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	1-m aerial			GPS	1-m aerial			
4	(S) S. Duff. Near to US 30 E Ramp	449573.192	449573.523	-0.331	0.109	4650307.519	4650305.426	2.093	4.382	4.492
10	(S) S. Duff Ave, near to Honda	449482.609	449481.495	1.114	1.241	4651746.287	4651746.466	-0.179	0.032	1.273
12	(S) Side Walk on S. Duff Ave near to Arby's	449450.627	449451.513	-0.886	0.784	4652028.556	4652026.458	2.098	4.402	5.186
13	(S) Sherman Ave & S. 2nd St	449314.241	449313.482	0.759	0.577	4652368.344	4652368.506	-0.162	0.026	0.603
15	(S) Kellogg Ave, Next to Parking Lot	449205.381	449205.478	-0.097	0.009	4652682.724	4652682.480	0.244	0.060	0.069
16	(S) Duff Ave, Near to RR Tracks	449454.858	449452.470	2.388	5.703	4652707.706	4652705.470	2.236	4.998	10.701
19	(S) Bus Stop on 5th St, near to City Hall	448834.862	448831.508	3.354	11.250	4652838.188	4652838.503	-0.315	0.099	11.349
20	(S) Grand Ave & 5th St	448670.555	448669.489	1.066	1.137	4652816.842	4652814.489	2.353	5.536	6.673
21	(S) Wilson Ave & 8th St	448803.795	448804.491	-0.696	0.485	4653174.395	4653174.440	-0.045	0.002	0.487
22	(S) Hodge Ave & 8th St	448551.849	448549.468	2.381	5.668	4653169.138	4653168.450	0.688	0.473	6.142
25	(S) Clark Ave & 13th St	448928.357	448927.546	0.811	0.658	4653795.310	4653794.516	0.794	0.631	1.289
26	(S) Harding Ave & 13th St	448564.538	448564.503	0.035	0.001	4653808.180	4653809.490	-1.310	1.716	1.717
27	(S) Wilson Ave & 16th St	448796.688	448795.466	1.222	1.493	4654224.130	4654224.446	-0.316	0.100	1.592
28	(S) Harding Ave & 16th St	448566.306	448565.477	0.829	0.687	4654209.802	4654210.470	-0.668	0.447	1.134
29	(S) Duff Ave & Jenson Ave	448806.332	448804.532	1.800	3.240	4655656.318	4655656.527	-0.209	0.044	3.284
31	(A) Access road on 28th St, next to Grand Ave	448676.460	448676.503	-0.043	0.002	4655436.730	4655435.483	1.247	1.556	1.558
32	(S) 30th St & Ferndale Ave	448322.970	448321.474	1.496	2.237	4655632.636	4655632.528	0.108	0.012	2.249
35	(S) Lincoln Way & Hazel Ave	448117.318	448116.490	0.828	0.685	4652513.587	4652515.501	-1.914	3.663	4.348
39	(S) S. 3rd St, next to parking lot	449384.305	449384.463	-0.158	0.025	4652206.772	4652206.512	0.260	0.068	0.093
40	(S) Kellogg Ave & S. 2nd St	449189.838	449190.522	-0.684	0.467	4652349.885	4652347.504	2.381	5.669	6.136
43	(S) Grand Ave & 12th St	448639.637	448637.496	2.141	4.583	4653666.658	4653665.466	1.192	1.420	6.003
44	(S) Murray Dr & Roosevelt Ave	448449.075	448446.553	2.522	6.361	4654331.022	4654331.542	-0.520	0.271	6.632
45	(S) Murray Dr & Northwestern Ave	448214.629	448214.462	0.167	0.028	4654329.490	4654330.442	-0.952	0.906	0.934
46	(S) Clark Ave & 18th St	448931.696	448932.567	-0.871	0.758	4654436.881	4654436.464	0.417	0.174	0.931

Table B.5: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in $X)^2$	Y - Coordinate		Diff in Y	(Diff in $Y)^2$	(Diff in $X)^2$+
		GPS	1-m aerial			GPS	1-m aerial			(Diff in Y)2
50	(S) Clark Ave & 6th St, Near to City Hall	448916.466	448915.501	0.965	0.931	4652927.871	4652925.477	2.394	5.733	6.663

Sum	91.539	m
Average	3.662	m
Average	11.984	ft
RMSE	1.914	m
RMSE	6.263	ft
NSSDA	3.312	m
NSSDA	10.840	ft

D = Drainage Structure

A = Access Road

S = Side Walk intersection

Notes:
A circle of 3.46 ft radius defines horizontal RMSE
Positional Accuracy: Tested 5.99 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 5.99 ft of its true location, as best as its true location has been determined 95% of the time.)

APPENDIX C. OBSERVER VARIATION

Table C.1: 2-inch Resolution Standard Deviation Among Observers for Signs

Signs (X Direction)	1	2	3	4	5	6
User 1	4891416.2830	4891302.8998	4888678.5251	4888617.8769	4888499.2486	4888386.7049
User 2	4891416.4452	4891302.8046	4888678.4278	4888617.7263	4888499.1598	4888386.5563
User 3	4891416.2952	4891302.8454	4888677.8504	4888615.3692	4888499.3058	4888386.5091
User 4	4891416.5138	4891302.9204	4888678.4784	4888617.8399	4888499.2527	4888386.6983
User 5	4891416.4056	4891302.8333	4888678.5255	4888617.3654	4888499.4370	4888386.5671
User 6	4891416.3668	4891302.7398	4888678.3736	4888618.1950	4888499.2259	4888386.4667
User 7	4891416.3137	4891302.7814	4888678.5530	4888618.0872	4888499.3992	4888386.6168
Standard Deviation	0.0722	0.1021	0.2394	0.9763	0.0722	0.0722
Minimum	**0.0722**	Feet				
Maximum	**0.9763**	Feet				

Signs (Y Direction)	1	2	3	4	5	6
User 1	3465660.9557	3469014.0649	3471447.8150	3474488.9172	3477016.2033	3481700.7224
User 2	3465660.9364	3469014.0816	3471447.8419	3474488.6675	3477016.1658	3481700.7958
User 3	3465660.9073	3469014.0642	3471446.9636	3474486.2543	3477016.1947	3481701.0627
User 4	3465661.1021	3469014.1959	3471447.8800	3474488.7164	3477016.4043	3481700.8041
User 5	3465660.9493	3469014.2436	3471447.7350	3474488.2234	3477016.3981	3481700.8879
User 6	3465661.1062	3469013.9876	3471447.5969	3474488.9935	3477016.1467	3481700.7922
User 7	3465660.9311	3469013.9938	3471447.8038	3474488.8008	3477016.5183	3481700.6068
Standard Deviation	0.1021	0.1021	0.3146	0.9669	0.1614	0.1443
Minimum	**0.1021**	Feet				
Maximum	**0.9669**	Feet				

Table C.2: 2-inch Resolution Standard Deviation Among Observers for Signals

Signals (X Direction)	1	2	3	4	5
User 1	4891436.2192	4891319.6900	4889458.0091	4888630.9998	4888587.5757
User 2	4891436.3331	4891320.8593	4889457.6298	4888630.4556	4888590.7991
User 3	4891435.0384	4891319.6531	4889456.7185	4888630.2390	4888587.6100
User 4	4891435.0842	4891319.6964	4889457.5491	4888630.4419	4888587.6450
User 5	4891434.7398	4891319.4043	4889457.3837	4888630.4910	4888590.5814
User 6	4891436.2428	4891319.7788	4889458.1853	4888630.0667	4888587.7572
User 7	4891434.9019	4891319.7197	4889458.1893	4888630.1406	4888587.7801
Standard Deviation	0.7027	0.5123	0.5534	0.1768	1.5472
Minimum	**0.1768**	Feet			
Maximum	**1.5472**	Feet			

Signals (Y Direction)	1	2	3	4	5
User 1	3463420.2340	3469379.7213	3471458.3101	3472873.6329	3475617.4045
User 2	3463420.6642	3469375.8259	3471458.7485	3472871.8681	3475619.2525
User 3	3463424.5359	3469380.2982	3471458.4049	3472872.6605	3475617.9865
User 4	3463424.5685	3469379.9745	3471458.6806	3472872.6645	3475618.0908
User 5	3463424.1468	3469379.6099	3471458.6994	3472872.7620	3475619.0838
User 6	3463419.8305	3469379.1495	3471458.5503	3472870.6436	3475617.8163
User 7	3463423.9370	3469379.6630	3471458.5788	3472872.5646	3475617.8505
Standard Deviation	2.1914	1.5190	0.1693	0.9312	0.6884
Minimum	**0.1693**	Feet			
Maximum	**2.1914**	Feet			

Table C.3: 2-inch Resolution Standard Deviation Among Observers for Drainage Structures

Drainage Structures *(X Direction)*	1	2	3	4	5	6
User 1	4891175.1950	4888534.9191	4888526.8078	4888281.7364	4888202.6872	4888467.7760
User 2	4891175.0806	4888535.2008	4888526.8436	4888281.9306	4888202.7362	4888468.9587
User 3	4891175.2721	4888534.9124	4888526.7123	4888281.7677	4888202.6754	4888468.7994
User 4	4891175.2617	4888534.9767	4888526.9251	4888281.6762	4888202.6847	4888468.9636
User 5	4891175.0276	4888534.8832	4888526.6772	4888281.7536	4888202.5921	4888468.8076
User 6	4891175.3846	4888534.9178	4888526.7119	4888281.6700	4888202.6196	4888468.7395
User 7	4891175.2765	4888534.9410	4888526.7130	4888282.1031	4888202.6903	4888468.8807
Standard Deviation	0.1443	0.1021	0.1021	0.1443	0.0000	0.4208
Minimum	**0.0000**	Feet				
Maximum	**0.4208**	Feet				

Drainage Structures *(Y Direction)*	1	2	3	4	5	6
User 1	3466141.5212	3471613.0461	3474093.1137	3475679.5906	3477014.2236	3481294.2581
User 2	3466141.6283	3471612.8294	3474092.9988	3475679.1967	3477014.1746	3481294.3378
User 3	3466141.5565	3471612.8884	3474093.0854	3475679.3767	3477014.1927	3481294.3794
User 4	3466141.3372	3471613.1576	3474093.1221	3475679.5353	3477014.2916	3481294.4027
User 5	3466141.4185	3471612.8166	3474093.0577	3475679.4143	3477014.1892	3481294.4437
User 6	3466141.7404	3471612.8562	3474093.1710	3475679.4790	3477014.1554	3481294.4012
User 7	3466141.5250	3471613.0218	3474093.0546	3475679.3114	3477014.1858	3481294.2821
Standard Deviation	0.1250	0.1443	0.0000	0.1350	0.0510	0.0884
Minimum	**0.0000**	Feet				
Maximum	**0.1443**	Feet				

Table C.4: 2-inch Resolution Standard Deviation Among Observers for Pedestrian Crossing

Pedestrian Crossing (X Direction)	1	2	3	4	5
User 1	4891405.9857	4890392.9218	4889547.6927	4888554.8282	4888538.8819
User 2	4891407.2728	4890393.1041	4889546.2878	4888555.0133	4888538.5178
User 3	4891407.0773	4890392.8300	4889544.5461	4888554.4240	4888538.7673
User 4	4891408.0481	4890393.4734	4889544.4165	4888554.7974	4888538.7773
User 5	4891407.8062	4890393.5848	4889545.4836	4888554.8464	4888535.4241
User 6	4891408.1278	4890393.0444	4889541.9597	4888554.8185	4888538.7223
User 7	4891407.9891	4890393.3336	4889544.7741	4888554.8935	4888538.8173
Standard Deviation	0.4402	0.2958	1.4620	0.1768	1.3486
Minimum	**0.1768**	Feet			
Maximum	**1.4620**	Feet			

Pedestrian Crossing (Y Direction)	1	2	3	4	5
User 1	3463508.5075	3470974.3125	3471442.9368	3472407.9468	3481689.8836
User 2	3463508.7392	3470974.1829	3471441.9452	3472407.8088	3481689.7720
User 3	3463509.2943	3470974.3355	3471443.2110	3472408.1451	3481689.7012
User 4	3463508.8362	3470974.4822	3471442.6905	3472407.9101	3481689.8082
User 5	3463508.5240	3470974.3583	3471443.0337	3472407.7204	3481689.9000
User 6	3463508.5299	3470974.2825	3471439.9042	3472407.6376	3481689.7245
User 7	3463508.9376	3470974.3238	3471442.7237	3472407.8235	3481689.6097
Standard Deviation	0.2976	0.0884	1.1536	0.1693	0.1021
Minimum	**0.0884**	Feet			
Maximum	**1.1536**	Feet			

Table C.5: 2-inch Resolution Standard Deviation Among Observers for Medians

Medians (X Direction)	1	2	3	4	5
User 1	4891322.0831	4891332.2108	4888551.8861	4888583.9287	4888494.4476
User 2	4891326.9961	4891332.4286	4888551.8117	4888583.8576	4888494.3809
User 3	4891328.0463	4891332.3495	4888551.7123	4888583.9623	4888494.3200
User 4	4891326.2855	4891332.3077	4888551.5902	4888583.8222	4888494.3484
User 5	4891327.4831	4891332.6162	4888551.9504	4888584.2134	4888494.5216
User 6	4891326.5669	4891332.1988	4888551.6593	4888583.8392	4888494.3925
User 7	4891326.7493	4891332.0264	4888551.6610	4888583.8047	4888494.3914
Standard Deviation	0.6471	0.1936	0.1768	0.1581	0.0000
Minimum	**0.0000**	Feet			
Maximum	**0.6471**	Feet			

Medians (Y Direction)	1	2	3	4	5
User 1	3464088.9332	3466087.0844	3471455.0011	3473129.2995	3481682.4606
User 2	3464088.7891	3466087.2491	3471454.8901	3473129.5286	3481682.5123
User 3	3464092.7156	3466087.2537	3471455.1484	3473129.1124	3481682.3823
User 4	3464089.0957	3466087.2426	3471455.0425	3473129.2218	3481682.2729
User 5	3464088.9002	3466086.7977	3471455.2084	3473128.9390	3481682.2665
User 6	3464089.3181	3466086.8161	3471455.3740	3473129.0029	3481682.2930
User 7	3464089.6034	3466086.8310	3471455.3464	3473129.0487	3481682.1958
Standard Deviation	1.3910	0.2224	0.1840	0.2041	0.1021
Minimum	**0.1021**	Feet			
Maximum	**1.3910**	Feet			

Table C.6: 2-inch Resolution Standard Deviation Among Observers for Intersections

Intersections (X Direction)	1	2	3	4	5	6
User 1	4891348.8909	4891265.4344	4889504.3492	4888594.3911	4888542.5731	4888503.8971
User 2	4891351.1944	4891263.1671	4889497.6317	4888592.8807	4888549.0614	4888503.9507
User 3	4891348.6567	4891263.0190	4889498.6493	4888591.1604	4888546.2619	4888505.0130
User 4	4891347.1040	4891263.9388	4889494.5305	4888588.3821	4888541.3197	4888504.6136
User 5	4891349.4631	4891263.1889	4889498.1736	4888593.8191	4888542.6159	4888504.6395
User 6	4891350.2735	4891259.8156	4889495.6432	4888593.3181	4888542.9486	4888502.0235
User 7	4891352.2366	4891265.5328	4889490.7686	4888587.4395	4888542.7910	4888500.0171
Standard Deviation	1.7093	1.9162	4.1870	2.7424	2.7214	1.8013
Minimum	**1.7093**	Feet				
Maximum	**4.1870**	Feet				

Intersections (Y Direction)	1	2	3	4	5	6
User 1	3463464.4587	3469411.2948	3471417.2806	3472838.3710	3475652.8413	3481061.4559
User 2	3463463.5146	3469414.7582	3471415.9855	3472839.2227	3475651.9613	3481064.0328
User 3	3463459.1704	3469412.3549	3471417.2943	3472839.1280	3475652.8893	3481062.2509
User 4	3463462.0362	3469411.0192	3471415.4170	3472838.4665	3475653.0924	3481060.4981
User 5	3463463.7839	3469416.0164	3471417.7333	3472840.7245	3475655.0796	3481068.0009
User 6	3463463.7362	3469410.7685	3471412.3290	3472836.6898	3475652.6711	3481072.8082
User 7	3463464.3109	3469408.4726	3471415.6681	3472837.0901	3475652.7393	3481061.5263
Standard Deviation	1.8653	2.5572	1.8364	1.3626	0.9682	4.4826
Minimum	**0.9682**	Feet				
Maximum	**4.4826**	Feet				

Table C.7: 2-inch Resolution Standard Deviation Among Observers for Driveways

Driveways (X-Direction)	1	2	3	4	5	6
User 1	4891317.1974	4891227.9568	4888845.3951	4888594.2708	4888516.5586	4888594.6140
User 2	4891317.0122	4891227.8418	4888844.8041	4888593.9978	4888517.7915	4888594.1824
User 3	4891316.4093	4891227.8864	4888843.9533	4888593.9017	4888516.9967	4888594.7929
User 4	4891316.9646	4891230.2464	4888844.5689	4888594.3381	4888517.0317	4888594.5267
User 5	4891317.2161	4891228.7499	4888846.1921	4888594.1440	4888517.9776	4888595.0973
User 6	4891317.7858	4891228.6263	4888844.8643	4888592.6337	4888517.3019	4888596.1103
User 7	4891317.8854	4891229.1530	4888844.6917	4888594.3310	4888517.3229	4888594.3341
Standard Deviation	0.5154	0.8720	0.6997	0.5995	0.4895	0.6455
Minimum	**0.4895**	Feet				
Maximum	**0.8720**	Feet				

Driveways (Y-Direction)	1	2	3	4	5	6
User 1	3467492.3632	3469899.6333	3471441.3420	3473987.7209	3476431.6918	3481047.4290
User 2	3467489.8350	3469899.9746	3471438.9138	3473985.3304	3476432.3740	3481047.1352
User 3	3467492.6241	3469900.8172	3471441.2082	3473984.2239	3476434.4528	3481047.7929
User 4	3467491.8778	3469898.0307	3471438.9566	3473986.3662	3476432.0255	3481047.6117
User 5	3467492.4207	3469903.0171	3471438.4261	3473987.9983	3476433.5100	3481047.3892
User 6	3467492.8733	3469899.7122	3471439.2657	3473985.8252	3476432.5482	3481047.1307
User 7	3467492.6846	3469900.4772	3471439.3866	3473983.4536	3476433.3147	3481047.2391
Standard Deviation	1.0458	1.5095	1.1558	1.6848	0.9629	0.2552
Minimum	**0.2552**	Feet				
Maximum	**1.6848**	Feet				

Table C.8: 2-inch Resolution Standard Deviation Among Observers for Utility Poles

Utility Poles (X Direction)	1	2	3	4	5	6
User 1	4891408.1491	4891213.6423	4890947.1496	4888564.7343	4888569.5331	4888554.6779
User 2	4891408.3027	4891213.3827	4890947.2038	4888564.8856	4888569.7963	4888554.8166
User 3	4891408.2076	4891213.4295	4890949.8776	4888564.6157	4888569.3024	4888554.7146
User 4	4891408.3766	4891213.8334	4890950.8062	4888564.6711	4888569.5354	4888554.8811
User 5	4891408.5784	4891214.1284	4890950.6525	4888564.8066	4888569.6460	4888555.0999
User 6	4891408.0440	4891213.4307	4890950.7908	4888564.7443	4888569.7075	4888554.3802
User 7	4891408.5308	4891213.5418	4890950.7629	4888564.6364	4888569.7214	4888554.8453
Standard Deviation	0.1909	0.2887	1.6925	0.0000	0.1614	0.2165
Minimum	**0.0000**	Feet				
Maximum	**1.6925**	Feet				

Utility Poles (Y Direction)	1	2	3	4	5	6
User 1	3463676.1445	3467598.5944	3471435.9797	3472649.9929	3475821.5005	3480810.8349
User 2	3463675.5696	3467598.3400	3471436.9864	3472649.9366	3475820.9673	3480810.4157
User 3	3463676.0902	3467598.9816	3471434.4493	3472649.8843	3475821.7018	3480810.9472
User 4	3463676.2130	3467598.4554	3471434.0748	3472649.8774	3475821.6483	3480810.7039
User 5	3463676.2095	3467598.7308	3471433.6848	3472650.1321	3475821.7167	3480811.3683
User 6	3463675.8919	3467598.3249	3471434.0087	3472649.6960	3475821.8706	3480811.0331
User 7	3463676.5253	3467598.7215	3471434.1637	3472650.2591	3475821.7500	3480810.8647
Standard Deviation	0.3019	0.2447	1.2290	0.1840	0.3019	0.2887
Minimum	**0.1840**	Feet				
Maximum	**1.2290**	Feet				

Table C.9: 2-inch Resolution Standard Deviation Among Observers for Bridges

Bridges (X Direction)	1	2	3	4	5
User 1	4891318.6069	4888645.3657	4888646.4213	4887517.3978	4885776.2483
User 2	4891318.2179	4888646.3400	4888660.9546	4887519.5417	4885777.1613
User 3	4891318.2415	4888645.4613	4888650.4197	4887511.4582	4885776.4362
User 4	4891318.7825	4888640.6009	4888648.6076	4887518.3558	4885776.5183
User 5	4891319.4423	4888645.7918	4888661.1290	4887519.1774	4885776.2502
User 6	4891317.8857	4888646.8904	4888657.2928	4887517.2458	4885775.8107
User 7	4891318.5693	4888645.5853	4888647.3708	4887518.9486	4885776.9679
Standard Deviation	0.5477	2.2749	6.2505	3.0465	0.4937
Minimum	**0.4937**	Feet			
Maximum	**6.2505**	Feet			

Bridges (Y Direction)	1	2	3	4	5
User 1	3467890.4211	3471935.9765	3472156.5922	3472775.4812	3471355.4866
User 2	3467894.3572	3471935.1805	3472157.1452	3472775.0056	3471355.8581
User 3	3467895.4369	3471935.9848	3472156.6346	3472775.3590	3471355.4338
User 4	3467890.5043	3471941.3014	3472159.1187	3472775.1041	3471356.4769
User 5	3467889.8704	3471936.7804	3472163.1100	3472776.8394	3471355.6166
User 6	3467895.4167	3471935.5144	3472162.2865	3472779.8599	3471355.9677
User 7	3467895.3118	3471936.3319	3472157.3344	3472777.1919	3471356.0671
Standard Deviation	2.6344	2.0835	2.7467	1.7470	0.3680
Minimum	**0.3680**	Feet			
Maximum	**2.7467**	Feet			

Table C.10: 2-inch Resolution Standard Deviation Among Observers for RR Crossings

RR Crossing (X Direction)	1	2	3	4
User 1	4891248.4761	4890356.3304	4889505.0133	4887326.7897
User 2	4891248.5400	4890361.8757	4889504.8936	4887326.8049
User 3	4891248.5546	4890361.2955	4889504.6938	4887326.5761
User 4	4891248.5619	4890362.2135	4889504.8849	4887327.0402
User 5	4891248.9421	4890362.5256	4889504.8205	4887326.8870
User 6	4891250.4552	4890360.5197	4889507.8249	4887325.7323
User 7	4891248.5564	4890362.1076	4889505.8457	4887326.7809
Standard Deviation	0.7542	0.7289	1.2145	0.4677
Minimum	**0.4677**	Feet		
Maximum	**1.2145**	Feet		

RR Crossing (Y Direction)	1	2	3	4
User 1	3472072.5914	3471880.2733	3471851.4034	3474064.2084
User 2	3472072.6609	3471880.9291	3471853.4450	3474063.8814
User 3	3472073.1309	3471881.6189	3471852.8241	3474063.5531
User 4	3472072.4584	3471880.9646	3471851.4882	3474064.5313
User 5	3472073.1386	3471881.4600	3471851.8628	3474064.7197
User 6	3472076.0014	3471882.6265	3471850.8171	3474063.4599
User 7	3472072.9794	3471881.5198	3471851.7227	3474064.0132
Standard Deviation	1.2290	0.7324	0.8985	0.4649
Minimum	**0.4649**	Feet		
Maximum	**1.2290**	Feet		

Table C.11: 6-inch Resolution Standard Deviation Among Observers for Signals

Signals (X Direction)	1	2	3	4	5
User 1	4891429.4897	4891316.5725	4889453.0912	4888629.1093	4888583.4879
User 2	4891429.0177	4891315.8762	4889453.5771	4888629.5589	4888584.7263
User 3	4891428.7752	4891315.7010	4889451.5431	4888629.3053	4888583.4524
User 4	4891428.7612	4891315.8330	4889452.2361	4888629.1334	4888584.2420
User 5	4891429.5364	4891316.5129	4889454.0111	4888629.9992	4888584.4012
User 6	4891429.0855	4891315.6447	4889449.9569	4888629.1982	4888583.5959
User 7	4891428.9654	4891315.8050	4889450.6226	4888629.1680	4888583.5804
Standard Deviation	0.2958	0.3062	1.6047	0.3354	0.5303
Minimum	**0.2958**	Feet			
Maximum	**1.6047**	Feet			

Signals (Y Direction)	1	2	3	4	5
User 1	3463424.0732	3469378.4464	3471455.5209	3472877.3266	3475622.4634
User 2	3463424.3135	3469378.7976	3471461.2452	3472877.7051	3475619.4926
User 3	3463424.7439	3469378.5608	3471455.0177	3472878.7064	3475620.1604
User 4	3463424.7089	3469379.2653	3471455.3908	3472878.1752	3475620.5241
User 5	3463423.8391	3469378.5135	3471458.4580	3472876.5991	3475620.3798
User 6	3463423.5693	3469378.2228	3471453.0636	3472877.3349	3475619.6623
User 7	3463424.6654	3469379.0487	3471456.5528	3472878.4912	3475620.4384
Standard Deviation	0.4649	0.3608	2.6624	0.7448	0.9736
Minimum	**0.3608**	Feet			
Maximum	**2.6624**	Feet			

Table C.12: 6-inch Resolution Standard Deviation Among Observers for Drainage Structures

Drainage Structures (X Direction)	1	2	3	4	5	6
User 1	4891167.5477	4888534.1084	4888524.7090	4888279.5125	4888200.6010	4888466.0258
User 2	4891167.4444	4888534.4836	4888524.0088	4888279.7846	4888201.0651	4888466.3411
User 3	4891167.6964	4888534.2186	4888524.7623	4888279.7498	4888200.5793	4888465.9625
User 4	4891167.5153	4888534.4536	4888524.9581	4888279.9154	4888200.6253	4888466.0834
User 5	4891167.3796	4888534.4579	4888524.5927	4888279.5427	4888200.5676	4888466.0577
User 6	4891167.5894	4888533.9886	4888524.6957	4888279.1807	4888200.2263	4888465.8146
User 7	4891167.8021	4888534.0202	4888524.6275	4888279.5935	4888200.3650	4888465.9470
Standard Deviation	0.1250	0.2041	0.3146	0.2282	0.2500	0.1614
Minimum	**0.1250**	Feet				
Maximum	**0.3146**	Feet				

Drainage Structures (Y Direction)	1	2	3	4	5	6
User 1	3466141.0081	3471614.8626	3474093.9011	3475681.4945	3477014.4221	3481295.0253
User 2	3466140.8999	3471614.7478	3474093.8526	3475681.6199	3477014.2808	3481294.7904
User 3	3466140.7340	3471614.7151	3474093.7614	3475681.6769	3477014.3136	3481294.7949
User 4	3466140.9436	3471614.5401	3474093.9889	3475681.5402	3477014.3314	3481295.0188
User 5	3466141.0480	3471618.9176	3474094.2094	3475681.4514	3477014.6301	3481295.0205
User 6	3466140.9405	3471615.0780	3474094.7230	3475682.2273	3477014.7574	3481295.2686
User 7	3466140.5569	3471614.9092	3474093.7711	3475681.6593	3477014.1758	3481294.9080
Standard Deviation	0.1840	1.5612	0.3423	0.2700	0.2104	0.1768
Minimum	**0.1768**	Feet				
Maximum	**1.5612**	Feet				

Table C.13: 6-inch Resolution Standard Deviation Among Observers for Pedestrian Crossings

Pedestrian Crossing (X Direction)	1	2	3	4	5
User 1	4891393.6795	4890389.7627	4889533.8357	4888556.0700	4888556.1634
User 2	4891395.8823	4890390.1412	4889540.6022	4888555.6021	4888565.2514
User 3	4891395.4603	4890390.1246	4889541.2335	4888555.0503	4888565.6854
User 4	4891395.7895	4890389.8255	4889540.1870	4888555.4011	4888565.4980
User 5	4891395.9093	4890389.6801	4889540.5292	4888555.4330	4888565.3405
User 6	4891395.3594	4890389.9557	4889540.7064	4888555.7897	4888565.8748
User 7	4891395.1628	4890390.2732	4889540.6685	4888555.4588	4888565.7111
Standard Deviation	0.3162	0.2236	0.3354	0.2236	0.2372
Minimum	**0.2236**	Feet			
Maximum	**0.3354**	Feet			

Pedestrian Crossing (Y Direction)	1	2	3	4	5
User 1	3463508.3758	3470974.7781	3471440.5225	3472414.4285	3479762.4866
User 2	3463508.0481	3470974.7300	3471440.7300	3472414.7464	3479762.4726
User 3	3463508.3308	3470974.8147	3471441.4494	3472414.0099	3479762.6479
User 4	3463508.6781	3470974.8612	3471441.2291	3472414.5912	3479763.0214
User 5	3463508.7863	3470974.6309	3471440.9800	3472414.6577	3479763.0861
User 6	3463507.8081	3470974.7256	3471440.7631	3472414.4333	3479762.7688
User 7	3463508.2825	3470974.8831	3471441.1250	3472414.3025	3479762.6784
Standard Deviation	0.3423	0.0884	0.3268	0.2447	0.2447
Minimum	**0.0884**	Feet			
Maximum	**0.3423**	Feet			

Table C.14: 6-inch Resolution Standard Deviation Among Observers for Medians

Medians (X Direction)	1	2	3	4	5
User 1	4891320.6609	4891324.3641	4888550.6286	4888581.3652	4888492.2136
User 2	4891326.9643	4891324.2586	4888550.0786	4888581.3435	4888491.9664
User 3	4891325.0827	4891324.4509	4888550.1164	4888581.5226	4888492.1069
User 4	4891324.9057	4891324.8331	4888550.0190	4888581.6218	4888492.0577
User 5	4891320.2053	4891324.8745	4888550.3369	4888582.0204	4888492.0669
User 6	4891325.3808	4891324.8368	4888550.3164	4888581.6571	4888491.1763
User 7	4891326.6492	4891323.9204	4888550.3974	4888582.0367	4888492.3752
Standard Deviation	2.4341	0.3953	0.1581	0.2850	0.3953
Minimum	**0.1581**	Feet			
Maximum	**2.4341**	Feet			

Medians (Y Direction)	1	2	3	4	5
User 1	3464080.6805	3466087.7527	3471455.9547	3473130.4631	3481684.7167
User 2	3464088.4511	3466088.4428	3471455.7970	3473130.4610	3481684.7971
User 3	3464090.4744	3466088.1618	3471455.7335	3473130.4907	3481685.3191
User 4	3464087.8705	3466087.8737	3471456.0585	3473130.2519	3481683.8958
User 5	3464080.6530	3466087.8851	3471456.0099	3473129.8968	3481685.8759
User 6	3464087.3538	3466087.6236	3471456.2403	3473129.9636	3481683.6816
User 7	3464088.5056	3466087.4127	3471455.9275	3473129.8944	3481683.1204
Standard Deviation	3.9575	0.3423	0.1614	0.2748	0.9682
Minimum	**0.1614**	Feet			
Maximum	**3.9575**	Feet			

Table C.15: 6-inch Resolution Standard Deviation Among Observers for Intersections

Intersections (X Direction)	1	2	3	4	5	6
User 1	4891342.4585	4891261.982	4889493.7677	4888590.0832	4888540.4256	4888506.3970
User 2	4891343.0317	4891261.2188	4889493.1708	4888590.3433	4888539.2110	4888503.4059
User 3	4891343.9718	4891260.9801	4889490.7233	4888589.6261	4888541.4111	4888502.5565
User 4	4891341.3746	4891261.0631	4889488.6187	4888586.4076	4888539.9240	4888501.0059
User 5	4891348.1420	4891262.6291	4889496.5009	4888581.0447	4888540.3761	4888495.8225
User 6	4891345.8420	4891262.4850	4889490.8585	4888589.0645	4888543.0849	4888501.1481
User 7	4891348.4151	4891261.3941	4889490.8837	4888587.4636	4888540.6069	4888506.0600
Standard Deviation	2.7783	0.6847	2.5921	3.2740	1.2395	3.5860
Minimum	**0.6847**	Feet				
Maximum	**3.5860**	Feet				

Intersections (Y Direction)	1	2	3	4	5	6
User 1	3463466.3597	3469411.9645	3471412.1744	3472846.2511	3475654.6654	3481063.1976
User 2	3463464.6028	3469410.7560	3471414.9311	3472844.0031	3475655.0586	3481061.8523
User 3	3463463.3171	3469411.7309	3471417.7698	3472848.8359	3475657.5621	3481066.0600
User 4	3463464.8228	3469412.0005	3471415.6582	3472845.5819	3475653.9263	3481062.5554
User 5	3463464.3466	3469415.5742	3471418.9306	3472846.7255	3475659.1792	3481069.6238
User 6	3463465.3299	3469406.4965	3471414.7484	3472843.9481	3475651.9201	3481061.1592
User 7	3463463.5517	3469410.1789	3471413.3823	3472844.4422	3475652.9315	3481059.5074
Standard Deviation	1.0383	2.7071	2.3552	1.7656	2.5510	3.3950
Minimum	**1.0383**	Feet				
Maximum	**3.3950**	Feet				

Table C.16: 6-inch Resolution Standard Deviation Among Observers for Driveways

Driveways (X Direction)	1	2	3	4	5	6
User 1	4891304.2155	4891226.7719	4888841.2236	4888590.1253	4888513.8428	4888590.8421
User 2	4891304.4528	4891226.9434	4888842.2252	4888591.2168	4888514.3333	4888592.0270
User 3	4891305.2553	4891226.4206	4888842.7283	4888591.5087	4888513.9100	4888591.8599
User 4	4891304.1313	4891226.7984	4888844.0054	4888590.9884	4888513.8641	4888591.8770
User 5	4891305.0170	4891227.0209	4888841.8092	4888589.5851	4888515.2705	4888590.5456
User 6	4891305.4054	4891224.9196	4888843.0781	4888591.4554	4888513.8890	4888591.3842
User 7	4891305.5511	4891226.5127	4888842.7354	4888591.4365	4888513.8916	4888590.7607
Standard Deviation	0.5907	0.7217	0.8985	0.7500	0.5254	0.6166
Minimum	**0.5254**	Feet				
Maximum	**0.8985**	Feet				

Driveways (Y Direction)	1	2	3	4	5	6
User 1	3467476.7647	3469901.9804	3471438.0456	3473987.2943	3476432.5509	3481046.8668
User 2	3467473.4550	3469901.9702	3471439.3767	3473986.0807	3476432.5792	3481046.8645
User 3	3467475.5206	3469903.8071	3471441.6306	3473984.7586	3476432.8260	3481047.8144
User 4	3467476.2585	3469901.6262	3471438.6944	3473987.8214	3476433.2110	3481047.3759
User 5	3467476.1122	3469904.9213	3471440.8510	3473986.6907	3476433.1508	3481047.4820
User 6	3467476.8659	3469903.4629	3471440.4476	3473986.3563	3476432.6623	3481046.2103
User 7	3467475.4447	3469902.2989	3471437.5539	3473985.2742	3476433.9061	3481047.0252
Standard Deviation	1.1603	1.2173	1.5198	1.0741	0.4841	0.5204
Minimum	**0.4841**	Feet				
Maximum	**1.5198**	Feet				

Table C.17: 6-inch Resolution Standard Deviation Among Observers for Bridges

Bridges (X Direction)	1	2	3	4	5
User 1	4891309.5828	4888642.7327	4888650.0722	4887505.3508	4885774.1681
User 2	4891308.7622	4888647.4007	4888661.1900	4887516.4156	4885774.5678
User 3	4891308.5672	4888643.6372	4888655.8258	4887509.1905	4885774.9200
User 4	4891309.1963	4888645.5106	4888654.1096	4887514.0340	4885777.4323
User 5	4891308.7280	4888647.7244	4888658.6692	4887493.8871	4885774.9159
User 6	4891308.6841	4888645.4266	4888655.7317	4887515.4029	4885776.2218
User 7	4891308.9843	4888644.3239	4888653.9544	4887503.6543	4885775.2056
Standard Deviation	0.2500	1.6279	2.8262	8.6948	1.0869
Minimum	**0.2500**	Feet			
Maximum	**8.6948**	Feet			

Bridges (Y Direction)	1	2	3	4	5
User 1	3467890.7956	3471941.7054	3472169.6550	3472794.5888	3471362.7614
User 2	3467895.0918	3471941.9042	3472168.9187	3472790.5118	3471356.2182
User 3	3467890.3917	3471943.3541	3472166.5020	3472791.4399	3471356.8386
User 4	3467892.1174	3471943.2119	3472170.5074	3472791.4866	3471357.7005
User 5	3467891.7392	3471948.4166	3472165.3727	3472790.8996	3471357.2500
User 6	3467895.4063	3471942.5995	3472169.9624	3472793.6202	3471358.7134
User 7	3467892.1065	3471941.9849	3472169.9085	3472791.7434	3471356.6798
Standard Deviation	1.9744	2.3408	1.9659	1.4939	2.2401
Minimum	**1.4939**	Feet			
Maximum	**2.3408**	Feet			

Table C.18: 6-inch Resolution Standard Deviation Among Observers for RR Crossings

RR Crossing (X Direction)	1	2	3	4
User 1	4891249.2711	4890359.2779	4889501.8563	4887323.2605
User 2	4891249.1975	4890359.4529	4889500.9020	4887323.3648
User 3	4891249.0187	4890359.2481	4889501.3049	4887323.2204
User 4	4891249.3451	4890360.0268	4889501.1527	4887323.1446
User 5	4891249.3217	4890359.7184	4889501.7302	4887322.9338
User 6	4891249.1969	4890359.0938	4889501.5442	4887323.2447
User 7	4891249.9696	4890360.1488	4889501.6697	4887323.0783
Standard Deviation	0.3446	0.4330	0.3260	0.1369
Minimum	**0.1369**	Feet		
Maximum	**0.4330**	Feet		

RR Crossing (Y Direction)	1	2	3	4
User 1	3472076.3216	3471878.0883	3471854.6963	3474065.3768
User 2	3472076.3055	3471877.8825	3471854.7555	3474067.3090
User 3	3472076.3261	3471878.7988	3471855.3455	3474067.3269
User 4	3472076.5086	3471878.4917	3471854.9364	3474067.4768
User 5	3472077.3164	3471878.7041	3471855.2097	3474067.3842
User 6	3472076.0280	3471878.2852	3471854.2226	3474068.0650
User 7	3472076.3995	3471878.1306	3471855.1143	3474067.4643
Standard Deviation	0.3986	0.3346	0.3750	0.8447
Minimum	**0.3346**	Feet		
Maximum	**0.8447**	Feet		

Table C.19: 24-inch Resolution Standard Deviation Among Observers for Intersections

Intersections (X Direction)	1	2	3	4	5	6
User 1	4891347.3032	4891262.6554	4889496.7778	4888580.8502	4888539.8803	4888502.8342
User 2	4891346.2106	4891260.9398	4889495.5211	4888588.6043	4888545.7960	4888502.0571
User 3	4891344.2311	4891262.2418	4889490.3612	4888587.5675	4888543.8399	4888500.1123
User 4	4891342.6945	4891261.8039	4889492.3810	4888592.1853	4888543.4126	4888498.9148
User 5	4891348.8421	4891261.8983	4889490.3172	4888585.8109	4888548.1971	4888501.9356
User 6	4891346.9768	4891262.8634	4889495.2945	4888591.1615	4888544.8429	4888502.2046
User 7	4891345.0254	4891264.4526	4889497.0927	4888587.8785	4888542.0106	4888502.8144
Standard Deviation	2.0716	1.0992	2.9056	3.7284	2.6722	1.4755
Minimum	**1.0992**	Feet				
Maximum	**3.7284**	Feet				

Intersections (Y Direction)	1	2	3	4	5	6
User 1	3463465.1545	3469408.1906	3471412.9369	3472842.1663	3475655.5445	3481063.9503
User 2	3463462.4247	3469410.7492	3471407.1002	3472839.5446	3475649.0695	3481061.5230
User 3	3463462.9701	3469409.0188	3471411.3805	3472842.5499	3475652.0510	3481064.2580
User 4	3463464.6247	3469409.6357	3471411.5067	3472842.3591	3475649.3929	3481061.3562
User 5	3463465.5497	3469413.9540	3471414.8684	3472841.8115	3475655.8591	3481072.2318
User 6	3463460.9898	3469409.3974	3471413.2018	3472840.7097	3475656.2517	3481057.7333
User 7	3463465.0485	3469410.9071	3471413.0699	3472842.8764	3475654.1614	3481064.0710
Standard Deviation	1.7124	1.8833	2.4612	1.1815	3.0465	4.4543
Minimum	**1.1815**	Feet				
Maximum	**4.4543**	Feet				

Table C.20: 24-inch Resolution Standard Deviation Among Observers for Bridges

Bridges (X Direction)	1	2	3	4	5
User 1	4891312.7085	4888621.9235	4888618.4594	4887509.2068	4885768.3440
User 2	4891311.9739	4888620.9479	4888618.7096	4887504.8359	4885795.4246
User 3	4891311.5602	4888643.4062	4888651.3619	4887524.8423	4885764.1760
User 4	4891310.0915	4888640.7602	4888647.4705	4887504.8996	4885788.0807
User 5	4891310.9894	4888616.1919	4888620.7329	4887495.4621	4885747.1489
User 6	4891310.9354	4888620.7257	4888660.1764	4887514.8779	4885775.4166
User 7	4891311.9699	4888623.5178	4888633.9423	4887516.0796	4885776.1614
Standard Deviation	0.7331	11.5005	16.9914	10.4397	17.2072
Minimum	**0.7331**	Feet			
Maximum	**17.2072**	Feet			

Bridges (Y Direction)	1	2	3	4	5
User 1	3467909.2160	3471956.8882	3472167.0422	3472794.4267	3471354.9466
User 2	3467899.9770	3471958.0734	3472167.3531	3472789.2750	3471350.0266
User 3	3467903.8445	3471937.0176	3472165.6099	3472794.6363	3471353.6122
User 4	3467890.9181	3471949.7175	3472164.1481	3472792.4669	3471354.4925
User 5	3467905.2270	3471954.4285	3472163.3181	3472793.4347	3471355.7187
User 6	3467908.4562	3471959.0357	3472169.4392	3472791.1766	3471359.2879
User 7	3467884.1561	3471953.0601	3472167.8053	3472792.8545	3471356.7958
Standard Deviation	9.4127	7.5765	2.1494	1.8868	2.8586
Minimum	**1.8868**	Feet			
Maximum	**9.4127**	Feet			

Table C.21: 24-inch Resolution Standard Deviation Among Observers for RR Crossings

RR Crossing (X Direction)	1	2	3	4
User 1	4891252.9907	4890362.5300	4889504.5649	4887326.4840
User 2	4891249.7918	4890359.7472	4889506.6169	4887327.6483
User 3	4891250.9609	4890360.7363	4889503.8604	4887326.9324
User 4	4891252.1202	4890361.1955	4889504.5203	4887325.7623
User 5	4891252.4501	4890361.4394	4889506.0898	4887326.0299
User 6	4891250.2560	4890359.0814	4889506.0695	4887326.1331
User 7	4891251.9150	4890358.5752	4889506.4748	4887327.1999
Standard Deviation	1.0753	1.1753	1.1347	0.7542
Minimum	**0.7542**	Feet		
Maximum	**1.1753**	Feet		

RR Crossing (Y Direction)	1	2	3	4
User 1	3472066.9277	3471868.5617	3471851.6110	3474066.1878
User 2	3472083.5719	3471875.4163	3471852.8575	3474064.6388
User 3	3472073.3879	3471876.0749	3471854.7688	3474065.0455
User 4	3472079.6145	3471876.7839	3471851.8376	3474065.2437
User 5	3472073.4517	3471878.4495	3471860.4470	3474066.6304
User 6	3472074.5087	3471874.3102	3471853.5953	3474066.2502
User 7	3472082.9913	3471880.5054	3471856.1121	3474066.6123
Standard Deviation	6.0037	3.7618	3.0818	0.8101
Minimum	**0.8101**	Feet		
Maximum	**6.0037**	Feet		

Table C.22: 1-meter Resolution Standard Deviation Among Observers for Intersections

Intersections (X Direction)	1	2	3	4	5	6
User 1	449480.2928	449467.1728	448931.9539	448656.9461	448646.8612	448644.6696
User 2	449480.8742	449466.7188	448928.4110	448657.4371	448648.9439	448645.3039
User 3	449480.8666	449467.4055	448927.9987	448657.8145	448647.2379	448645.7957
User 4	449479.8741	449468.3572	448929.5702	448658.3868	448647.1294	448643.0106
User 5	449481.0033	449467.8452	448927.7321	448655.6489	448646.8612	448644.9655
User 6	449481.3709	449467.7464	448926.7437	448655.0794	448647.1676	448643.3920
User 7	449481.0109	449467.4992	448928.7048	448658.1095	448647.1479	448644.0259
Standard Deviation	0.5038	0.5216	1.6672	1.2583	0.7248	1.0186
Minimum	**0.5038**	Meters	**1.6528**	Feet		
Maximum	**1.6672**	Meters	**5.4700**	Feet		

Intersections (Y Direction)	1	2	3	4	5	6
User 1	4650073.5313	4651888.9076	4652503.0437	4652938.6765	4653795.4304	4655442.3866
User 2	4650073.7384	4651888.8591	4652502.3925	4652938.3774	4653794.5740	4655443.4704
User 3	4650073.9422	4651888.7913	4652501.7535	4652938.7596	4653794.9837	4655443.0109
User 4	4650074.0404	4651888.6767	4652502.2229	4652939.2178	4653793.5802	4655441.8801
User 5	4650075.0745	4651890.2452	4652502.9523	4652939.2583	4653794.9080	4655443.2184
User 6	4650074.2431	4651888.0518	4652502.7382	4652938.9670	4653795.3339	4655442.9356
User 7	4650073.6188	4651889.6595	4652501.7584	4652938.2186	4653794.1642	4655441.8465
Standard Deviation	0.5204	0.7144	0.5254	0.3953	0.6535	0.6495
Minimum	**0.3953**	Meters	**1.2969**	Feet		
Maximum	**0.7144**	Meters	**2.3439**	Feet		

Table C.23: 1-meter Resolution Standard Deviation Among Observers for Bridges

Bridges (X Direction)	1	2	3	4	5
User 1	449478.2413	448672.2175	448668.1311	448327.6136	447796.1233
User 2	449478.7559	448663.2836	448667.2981	448316.0070	447791.6182
User 3	449477.5013	448672.2372	448674.1602	448324.1708	447793.8983
User 4	449478.7215	448669.6766	448675.8061	448327.7068	447798.0235
User 5	449478.1597	448662.5398	448664.8807	448322.1230	447796.0741
User 6	449477.7775	448671.6950	448675.0191	448329.7428	447798.4954
User 7	449478.8520	448671.8898	448675.9613	448329.2279	447799.1348
Standard Deviation	0.5694	4.4669	4.8279	5.2414	2.9500
Minimum	**0.5694**	Meters	**1.8680**	Feet	
Maximum	**5.2414**	Meters	**17.1961**	Feet	

Bridges (Y Direction)	1	2	3	4	5
User 1	4651424.6315	4652668.8377	4652731.7046	4652924.1818	4652491.9546
User 2	4651424.0502	4652669.3183	4652730.4612	4652923.7937	4652492.5534
User 3	4651424.8630	4652664.7294	4652729.6313	4652923.8562	4652491.1769
User 4	4651425.6443	4652666.5500	4652730.6743	4652923.4837	4652492.0997
User 5	4651423.2376	4652669.5143	4652731.2289	4652923.2176	4652490.8258
User 6	4651422.9747	4652673.4841	4652731.6564	4652927.3643	4652492.7346
User 7	4651429.3331	4652665.4310	4652731.2007	4652923.8447	4652492.0158
Standard Deviation	2.1397	2.9922	0.7395	1.4087	0.6884
Minimum	**0.6884**	Meters	**2.2587**	Feet	
Maximum	**2.9922**	Meters	**9.8168**	Feet	

Table C.24: 1-meter Resolution Standard Deviation Among Observers for RR Crossings

RR Crossing (X Direction)	1	2	3	4
User 1	449466.7915	449197.3609	448935.4203	448274.6515
User 2	449466.3409	449196.4551	448933.2128	448274.6916
User 3	449465.0017	449195.2983	448933.7677	448275.1338
User 4	449466.3140	449195.3139	448935.2195	448274.8025
User 5	449466.8751	449195.5704	448936.0116	448275.2518
User 6	449468.9255	449195.4613	448935.3138	448273.9050
User 7	449465.9389	449195.3371	448935.1877	448275.1062
Standard Deviation	1.3128	0.4447	1.0622	0.4942
Minimum	**0.4447**	Meters	**1.4590**	Feet
Maximum	**1.3128**	Meters	**4.3071**	Feet

RR Crossing (Y Direction)	1	2	3	4
User 1	4652700.5079	4652641.6764	4652635.3785	4653313.1727
User 2	4652700.3192	4652641.7748	4652635.9619	4653314.8282
User 3	4652700.7860	4652641.6532	4652636.3649	4653314.2290
User 4	4652700.8474	4652641.7001	4652635.9373	4653314.9874
User 5	4652700.7139	4652641.7900	4652636.5897	4653314.5858
User 6	4652701.0599	4652641.1951	4652636.0531	4653315.1381
User 7	4652699.9307	4652641.3971	4652635.5902	4653314.8422
Standard Deviation	0.3750	0.2165	0.4208	0.6693
Minimum	**0.2165**	Meters	**0.7103**	Feet
Maximum	**0.6693**	Meters	**2.1957**	Feet

APPENDIX D. TIME COMPARISONS

The time taken to inventory features from the aerial photographs is compared to the time taken to inventory the same number of features in the field using a GPS unit. The time taken for each test subject to identify features on the aerial photographs was recorded during the user test. The time taken to collect GPS coordinates using a RTK system on the ground was recorded during data collection. These two times were then compared and the results are presented in Tables D.1, D.2 and in Figure D.1.

Table D.1: Time taken for each user per data set in minutes

	Resolution (# points)			
	2-inch (54)	6-inch (42)	24-inch (15)	1-meter (15)
User 1	65	40	9	7
User 2	41	34	7	11
User 3	55	28	8	6
User 4	25	20	5	7
User 5	35	50	25	15
User 6	49	22	7	11
User 7	38	45	8	17
Average	**44**	**34**	**10**	**11**

Table D.2: Time comparison with RTK GPS method

	2-inch	6-inch	24-inch	1-meter	GPS
Minutes/point	0.81	0.81	0.66	0.70	12.00

It can be observed from Figure D.1 that the time taken for data collection per point is less if using remote sensing method than the GPS method.

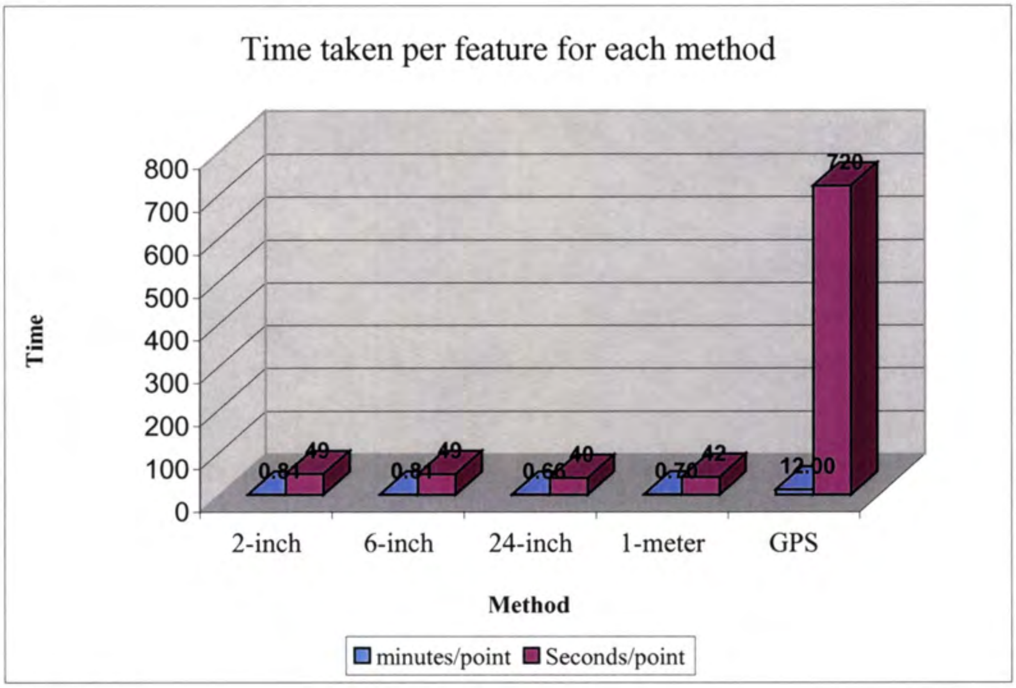


Figure D.1: Time comparisons for each method

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